



<http://researchcommons.waikato.ac.nz/>

Research Commons at the University of Waikato

Copyright Statement:

The digital copy of this thesis is protected by the Copyright Act 1994 (New Zealand).

The thesis may be consulted by you, provided you comply with the provisions of the Act and the following conditions of use:

- Any use you make of these documents or images must be for research or private study purposes only, and you may not make them available to any other person.
- Authors control the copyright of their thesis. You will recognise the author's right to be identified as the author of the thesis, and due acknowledgement will be made to the author where appropriate.
- You will obtain the author's permission before publishing any material from the thesis.

Signalled Delay to Reinforcement in Delayed Matching to Sample

A thesis

Submitted in partial fulfilment
of the requirements for the degree
of

Master of Applied Behaviour Analysis

at

The University of Waikato

By

Lauren Scafturis

THE UNIVERSITY OF WAIKATO

2012

Abstract

Five hens were trained on a delayed matching to sample task. The retention intervals started at 0.25 s and were gradually increased until they were 1 s, 2 s, 4 s and 8 s in each session. At the end of training the fifth response to the sample stimulus (red or green square) extinguished the key light and initiated one of the delays which were quasi-randomly selected. At the end of the retention interval the comparison stimuli were presented: a red and a green square. A response to the comparison stimulus that matched the sample stimulus resulted in 3-s access to wheat. An incorrect match resulted in a 3-s blackout. There was then an intertrial interval of 10-s regardless of the trial outcome. Accuracy remained consistently high across all the delays. The percentage of correct responses at the 8-s delay interval remained above 70%. Once behaviour was stable a cue was inserted into the retention interval. The blue key with a cross on it signalled that a correct response would receive reinforcement delayed by 2.5-s. A yellow key with a vertical line on it signalled that a correct response would receive reinforcement immediately. It was hypothesised that signalling a delay to reinforcement would decrease response accuracy on those trials. No differences in response accuracy were found for the different cues indicating that the cue did not affect response behaviour. In the next condition the blue cue now signalled that a correct response would result in 0.5 s access to wheat. The yellow cue now signalled a correct response would be followed by 4.5-s access to wheat. Accuracy for the small and large reinforcer remained the same. Through each condition matching accuracy remained between 60 and 80% regardless of the length of the retention interval. It is thought the gradual increases in retention interval length during training may have been responsible for the maintained high accuracy.

Acknowledgments

My grateful thanks to my supervisors Professor Mary Foster and Dr. James McEwan for the long hours spent going over my pages of work, all the feedback and support over the past year, and for putting up with the neurotic student you inherited! Special thanks go to Jenny Chandler and Rob Bakker for the hours spent on my experiment and program, your expertise and input were invaluable. Thank you to Joshua Levine for your help and guidance during the data analysis process. To the students at the lab, a huge thank you, not only for the efficient running of the lab and experiments but also for creating friendships that made the long hours of work less stressful and so much more enjoyable.

To Dad and Mom & Kim and Steve, thank you to all of you for the continuous love and support through this whole process and for putting up with the array of chicken stories and tirades! I am so lucky to have parents as amazing you: that have encouraged me, given me perspective and advice, and provided me with comfort not only on the bad days but on the good days as well.

To my husband, Andy, I could not have done this without you! I cannot say thank you enough for all the support, patience and interest that you have shown, not only in the last year but through all my years of study – you are my everything. Thank you for always understanding the hours I had to spend on studying, for pushing me to believe in myself, always being proud of me and loving me so unconditionally. Love you always.

Huge appreciation goes to the staff at the Cambridge Early Learning Centre, who has employed me for the duration of my study and have always supported and encouraged me. I am so lucky to have a job that I enjoy. Grateful

thanks in particular to Lauren and Wendy for giving me time off when I needed it and being so accommodating with the rosters.

My friends, who are like my family, deserve special mention as they are never short of love and kind words. Jen and Jess, you continue to be my rocks, thank you for all that you do always.

Table of Contents

Abstract.....	i
Acknowledgments.....	ii
Table of Contents.....	iv
List of Figures	vi
Experiment 1.....	23
Method	23
Subjects.....	23
Apparatus.....	23
Procedure.....	24
Measures.....	26
Results.....	26
Discussion.....	38
Experiment 2.....	41
Method	41
Subjects.....	41
Apparatus.....	41
Procedure.....	41
Results.....	42
Discussion.....	52
Experiment 3.....	55
Method	55
Subjects.....	55
Apparatus.....	55
Procedure.....	55
Results.....	56
Discussion.....	65
Summary and Conclusions.....	68
References	74

Appendix A.....	78
Appendix B.....	79

List of Figures

Figure 1: Log d for the matching-to-sample plotted against session number for all birds.	28
Figure 2: Log c for the matching-to-sample sessions plotted against session number for all birds.	29
Figure 3: Mean log d as a measure of mean discriminability for delay training: (A) 1 s delay, (B) 2 s delay, (C) 4 s delay, and (D) 8 s delay for bird 11.1.	32
Figure 4: Mean log d as a measure of mean discriminability for delay training: (A) 1 s delay, (B) 2 s delay, (C) 4 s delay, and (D) 8 s delay for bird 11.2.	33
Figure 5: Mean log d as a measure of mean discriminability for delay training: (A) 1 s delay, (B) 2 s delay, (C) 4 s delay, and (D) 8 s delay for bird 11.3.	34
Figure 6: Mean log d as a measure of mean discriminability for delay training: (A) 1 s delay, (B) 2 s delay, (C) 4 s delay and (D) 8 s delay for bird 11.4.	35
Figure 7: Mean log d as a measure of mean discriminability for delay training: (A) 1 s delay, (B) 2 s delay, (C) 4 s delay and (D) 8 s delay for bird 11.6.	36
Figure 8: Mean discriminability for the 1 s, 2 s, 4 s and 8 s delay for each bird for the last 6 sessions.	37
Figure 9: Log d as a measure of discrimination for delay to reinforcement and no delay to reinforcement for each retention interval for all birds from the last 12 sessions.	46
Figure 10: Log c as a measure of response bias for delay to reinforcement and no delay to reinforcement for each retention interval for all birds from the last 12 sessions.	47
Figure 11: Percent correct as a measure of matching accuracy for delay to reinforcement and no delay to reinforcement for each retention interval for all birds from the last 12 sessions.	48
Figure 12: Mean log d for delayed matching to sample (baseline) from the last 6 sessions against mean log d for delay to reinforcement and no delay to reinforcement from the last 12 sessions across all retention intervals for all birds.	49

Figure 13: Total number of pecks to each cue across all retention intervals from the last 6 sessions of delay to reinforcement and no delay to reinforcement for all birds.....	50
Figure 14: Programmed retention interval lengths against the obtained retention interval lengths for each bird for delay to reinforcement and no delay to reinforcement from a single session.	51
Figure 15: Mean $\log d$ values for each cue across all retention intervals for the small reinforcer and the large reinforcer from the last 12 sessions for all birds.....	59
Figure 16: Mean $\log c$ for the small reinforcer and large reinforcer across all retention intervals from the last 12 sessions for all birds.	60
Figure 17: Mean percent correct for the small reinforcer and large reinforcer across retention intervals from the last 12 sessions for all birds.....	61
Figure 18: Mean $\log d$ from the last 6 sessions of Experiment 1 and the mean $\log d$ from the last 12 sessions with the small reinforcer and large reinforcer plotted across retention intervals for all birds.	62
Figure 19: Total number of pecks to each cue for signalled magnitude from the last 6 sessions for all birds across all retention intervals.	63
Figure 20: Obtained retention interval lengths against programmed retention interval lengths for the small reinforcer and large reinforcer across all birds for all retention intervals.....	64

White (in press) pointed out there has been much research on human and non-human animal memory. In studying both human and animal memory the most significant parameter involved is the passage of time – the temporal distance between original learning and later remembering; this is known as the retention interval. Various procedures have been used to study memory, some of which fall under the area of psychophysics; a field of psychology that involves studying perception (Stubbs, 1968). The aim of psychophysics is to measure the subjective experiences an organism has of a physical event (White, 2002). Procedures used to study animal memory in psychophysics include conditional discrimination, matching to sample and delayed matching to sample. These procedures are designed to test the abilities of animals to discriminate between stimuli.

Fetterman (1995) discusses the importance of such psychophysical procedures in understanding the memory processes of animals. He suggests studying them can help address issues such as how animals remember. If an animal can discriminate between concurrently available stimuli this shows the animal is remembering (White, in press). The discrimination made by the animal is commonly based on the reinforcement that is available for choosing one alternative over another. The animal learns that behaviour in the presence of a certain stimulus results in reinforcement. This stimulus becomes a discriminative stimulus (Martin & Pear, 2007; Stubbs, 1968). Stimuli come to exert control over the responses made by the animal learning that their presence signals the availability of reinforcement (Blough, 1959).

Conditional discriminations are often used in the study of memory processes. When presented with concurrently available stimuli the animal is required to select one: correct selections are followed by reinforcement. Various

procedures are used to teach conditional discriminations, with one of the most common being Matching-to-Sample (MTS). In a typical MTS trial the animal, such as a pigeon, is presented with three keys to peck: the middle key (the sample) is illuminated with a colour and a peck to this illuminated key extinguishes it and illuminates the two side keys. One of these side keys matches the sample key colour, the other key does not. A peck to the side key that matches the sample receives reinforcement; a peck to the key that does not match the sample receives no reinforcement.

The MTS procedure requires the animal to make an initial response to the sample stimulus before the comparison stimuli are presented: the sample stimulus is a conditional stimulus whilst the comparison stimuli are the discriminative events. The contingency is that the response to the stimulus that matches the sample stimulus results in reinforcement, a response to the other stimulus gives a timeout (Cooper, Heron & Heward, 2007). These contingencies teach the animal the conditional discrimination required for MTS. Measures of accuracy are used to show discrimination in MTS procedures: correctly matching each of the two stimuli indicates that the animal can discriminate between stimuli.

In memory tasks, the to-be-remembered stimulus is initially shown at the beginning of the trial and then again with the choice alternatives after a period of time. The discrimination involves both the stimuli and alternatives, and is conditional because correctly discriminating between stimuli results in reinforcement. The stimulus that is to be remembered exerts control over the choice the animal makes, based on a history of learning, the choice results in reinforcement.

The classic approach to animal memory, in terms of discrimination, holds that remembering decreases over time. The most common procedure used to study remembering in animals is Delayed Matching to Sample (DMTS), a procedure designed to test animal memory by providing an intentional delay between the initial presentation of the sample stimulus and the later presentation of the comparison stimuli. Blough (1959) used the DMTS procedure with pigeons. In this study pigeons were presented with a sample stimulus: either a steady light or a flickering light. A retention interval was initiated once the sample stimulus was presented, ranging from 0 s to 10 s in length. The comparison stimuli were then presented to the pigeon; one key with the steady light, the other key with the flickering light, and the pigeon was required to make a choice. Correctly matching the comparison to the sample stimulus resulted in reinforcement. The most significant finding reported was that response accuracy decreased as the delay interval increased, showing that the birds discriminated less accurately at longer delays.

As Harper and White (1997) state, the DMTS procedure is essentially made up of five phases. Each trial follows a set sequence of events: first, the animal is presented with a sample stimulus, which is then removed following a response to the sample. Upon the sample being removed a delay interval is initiated after which the animal is presented with comparison stimuli and is required to make a choice, i.e., to match the comparison stimuli to the sample stimuli. Correct responses may be followed (sometimes intermittently) by a reinforcer. Incorrect responses may be followed by a blackout period. Independent of the outcome of the trial, an intertrial interval then occurs before the next trial starts.

In a straightforward DMST trial the subject is presented with three keys. Upon the start of the trial, the centre key lights up, typically either green or red. A response to the centre key may be required to start the delay or retention interval. Once the retention interval is initiated all keys are turned off until the interval is over. Following the delay the two side keys are illuminated, one in red and one in green, the subject must make a choice between the two keys to match the sample with the comparison. If the subject makes a correct response it receives reinforcement, if it makes an incorrect choice it does not receive reinforcement. At the end of the trial there is an intertrial interval where the chamber is usually darkened with all keys turned off. As previously stated, the common finding is that accuracy decreases when the delay interval is increased (Blough, 1959; Sargisson & White, 2007; White, 2001).

The DMTS procedure has been used to study the effects of the manipulation of a range of variables, including manipulations of size and probability of reinforcers, as well as the length of retention intervals. A common manipulation of reinforcement involves changing the size or magnitude of the reinforcer. Manipulating the magnitude of reinforcement is a way of manipulating the value of the outcome on delayed matching trials. Some studies have used different reinforcer magnitudes on different trials during a DMTS procedure, and have signalled whether a large or small reinforcer was due on that trial prior to a response to the comparison stimuli. Both auditory and visual stimuli have been used as cues. The effects of cueing reinforcer size have become known as the Signalled Magnitude Effect, these studies are discussed next.

Nevin and Grosch (1990) used pigeons to study the signalled magnitude effect. Pigeons were trained on a DMTS procedure with red and green key lights

as stimuli; on half the trials an auditory stimulus was presented during the retention interval which was correlated with delivery of a large reinforcer: 4-5 s access to wheat. A different auditory stimulus accompanied the other half of trials and this was correlated with delivery of a small reinforcer: 1-5 s access to wheat. Results showed that accuracy for all birds was higher on trials where the large reinforcer was cued and lower on trials where the small reinforcer was signalled. These findings are consistent with other studies investigating the signalled magnitude effect (Brown & White 2005; Harnett, McCarthy & Davison, 1984; McCarthy & Voss, 1995; White and Brown, 2011).

McCarthy and Voss (1995) trained pigeons to perform on a DMTS procedure where reinforcer magnitude was signalled by houselights in their first condition and then unsignalled in the second condition. In the first condition each trial began with the illumination of the centre key in white: a single peck to the key removed the white light and produced either a red or a green light on the key. The key was lit for 5 s and was accompanied by the illumination of one of the side house lights. The left houselight signalled a 1.5-s reinforcer (small) for correct responses while the right houselight signalled a 4.5-s reinforcer (large) for correct responses. If the small reinforcer was signalled the hopper lit up blue and if the large reinforcer was signalled the hopper lit up yellow. After the centre key was lit for 5s the key extinguished and a retention delay of 0.5 s, 1.5 s, 4 s or 12 s occurred. The houselight was turned on at the same time as the sample and stayed on until the first peck to either of the comparison stimuli after the retention interval. Once the interval was over the comparison stimuli were presented. Correct matches resulted in the reinforcement signalled by the houselight. In the second condition the correlation between the houselights and reinforcement was removed so that the large and small reinforcers occurred equally. Results of

Condition 1 showed higher accuracy on the trials with signalled large reinforcers than on the trials that signalled small reinforcement. Accuracy was also higher on the signalled trials in Condition 1 than on the unsignalled trials in Condition 2 suggesting that signalling reinforcer magnitude provides incentive to respond more accurately.

In summary, the above studies suggest that signalling reinforcer magnitude increases response accuracy in a DMTS procedure: when a large reinforcer is signalled accuracy is higher than on trials where a small reinforcer is signalled.

Another aspect of reinforcement that has been manipulated in DMTS procedures is probability: the likelihood of receiving reinforcement for a choice or response. The effects of reinforcer probability on performance have been studied in relation to rate of forgetting and discriminability (Brown & White, 2009). Brown and White (2005) used pigeons to determine whether performance on a DMTS procedure is affected by signalling the probability of reinforcement for correct responses. After a pigeon was presented with the sample stimulus, the sample was replaced by a cue, either a vertical line or a cross. The vertical line signalled a reinforcer probability of 1.0 (greater probability) while the cross signalled a reinforcer probability of 0.2 (smaller probability). Results showed that accuracy was higher on trials on which the larger reinforcer probability was signalled, much like the results found for the signalled magnitude effect. These findings are consistent with the results found by Brown and White (2009) and Mazur (1991) who also investigated the effects of signalled probabilities on performance. Signalling a higher probability of receiving reinforcement appears to produce similar results to signalling a large reinforcer; accuracy is higher on trials that signal a higher probability or larger reinforcer.

There are a range of theories of remembering in the literature. The classic approach to remembering holds that if information can be recalled after a period of time then remembering has occurred. Tulving and Thomson (1971) state that in order to remember something it must be properly encoded and stored to allow for successful retrieval at a later time. Successful encoding of information requires that the information be rehearsed in the time interval between learning and retrieval. Manipulating the variables in a DMTS procedure allows for new theories of memory to be investigated that differ from the classic theories of memory, approaching memory theory using behavioural principles, leading to behavioural theories on memory including delay specific remembering and temporal independence.

White (in press) argues that remembering is discrimination that occurs at the time of learning, making remembering at a certain delay specific to that delay. White (in press) refers to this as delay specific remembering. Delay specific remembering is supported through a theory called temporal independence. Temporal independence suggests that performance at one retention interval can be independent of performance at another regardless of the length of the intervals: performance can be higher at a longer retention interval than at a shorter retention interval. Sargisson and White (2001) trained pigeons on a DMTS procedure using a specific retention intervals of 0, 2, 4 and 6 s. Test sessions were introduced after training that consisted of unreinforced trials for delay intervals of 0, 2, 4, 6, 8, and 10 s. The results for the test session differed from the usual findings: instead of accuracy decreasing as the interval increased, accuracy peaked at the intervals at which training had occurred. Sargisson and White (2001) argued that this finding suggests that remembering can be trained at different retention intervals and that generalisation to similar delays occurs.

Delay specific remembering as shown by temporal independence provides evidence for the view held by White (2001, in press) and White and Brown (2011) that the temporal distance between learning and remembering forms part of a complex stimulus that makes up the to-be-remembered event. The stimulus that exerts power over discrimination is made up of all the aspects of the event: the sample stimulus, comparison stimuli, the retention interval and the reinforcement. White (2002) states that, based on a history of learning, discrimination becomes specific to the interval where remembering occurs due to the presence of the stimuli that made up the whole event at the time that learning first took place. For example, performance at different retention intervals has been found to be related to the availability or probability of reinforcement at the interval of choice (White, in press). If the probability of receiving reinforcement is higher at one retention interval than at another, the choice that is made may be related to the reinforcement available, based on a history of learning, regardless of whether the interval is long or short. This is evident in the Sargisson and White (2001) study above and provides support for White's (in press) theory about a compound stimulus.

White and Cooney (1996) used pigeons on a DMTS procedure to study performance at different retention intervals. Comparison stimuli were presented at two retention intervals: one short at 0.1s and one long at 4s. In one of the conditions the probability of receiving reinforcement was held constant and equal for correct red and correct green responses at the short delay, while at the long retention interval the probability for correct choices for red and green varied. In the other condition probabilities were varied for the short interval and remained constant at the long interval. The results indicated that the choices were influenced by the reinforcer probability related to green or red responses at the

specific delay. The study showed that the choices made were influenced by reinforcer ratios that were directly related to the choice: the interval associated with a higher probability of reinforcement was chosen over the interval associated with the smaller probability of reinforcement, regardless of retention interval length. This adds support for the idea of a compound stimulus influencing responding.

Delay specific remembering and temporal independence contradict the classic memory theory by suggesting that remembering does not necessarily decrease with increasing retention intervals. Behavioural studies on memory such as the ones above are “characterised by inclusion of reinforcement as the major determinant of performance, so they can account for reinforcement influences on forgetting functions” (White, in press, p.37). As mentioned, it has been shown that both rate and magnitude of reinforcement can influence accuracy in DMTS. In order to investigate the effect reinforcement has on response accuracy at a specific delay, White and Brown (2011) used a variation of the signalled magnitude effect. They used pigeons in a study that examined the reversal of the signalled magnitude effect in a DMTS procedure.

The aim of their study was to examine whether the signalled magnitude effect would reverse following reversal of the cues used to signal the size of the reinforcers available. Each trial began with either a red or green sample, once the pigeon had pecked the sample five times; the centre key presented either a diagonal cross or a vertical line symbol. These symbols indicated the size of the reinforcer that was available for correct responses on trials following the symbol presentation: the diagonal cross signalled that there was a 0.5-s access to wheat (small reinforcer) for correct response, the vertical line signalled a 4.5-s access to

wheat (large reinforcer) was available for correct responses. The reinforcer cues were signalled over retention intervals of 1, 2, 4, and 8 s. The first peck to the centre key turned off the sample stimulus: the peck to the centre key was required in order to expose the animal to this stimulus. After the retention interval ended the two side keys were illuminated, one red and one green, and the pigeons were required to peck one of these. Correct choices were immediately followed by either a 0.5-s or 4.5-s access to food depending on the cue that had been present during the retention interval on the trial. Incorrect responses resulted in either a 0.5-s or 4.5-s blackout, depending on the cue. An intertrial interval of 15 s occurred before the next trial regardless of the outcome.

During test sessions, the procedure was much the same except on half the trials the cue that signalled the reinforcer size was reversed part way through the retention interval. The cues were swapped after 2 s during the 4-s and 8-s intervals, the 1-s and 2-s delays did not involve a cue reversal as the retention intervals were too short. The results of the study indicated that the pigeon's matching was more accurate when the larger reinforcer was cued than when the smaller reinforcer was cued, a result consistent with other studies of the signalled magnitude effect. When the cues were switched from the large reinforcer cue to the small reinforcer cue after 2 s accuracy was low at 4 and 8 s but high at 1 and 2 s. However, when the cues were switched from the small reinforcer cue to the large reinforcer cue after 2 s, the pigeon's accuracy was low at 1 and 2 s but higher at 4 and 8 s.

The results of this study provide evidence for delay specific remembering: the "dissociation of forgetting from the passage of time" (White, 2002, p.2). The reversal of the signalled magnitude effect shows that discrimination at one delay

interval can be temporally independent to the discrimination at another retention interval and that variable reinforcement influences performance (White & Brown, 2011). This is suggested by the increase in accuracy when cues were switched from the small reinforcer to the large reinforcer. Thus, by using a variation of the signalled magnitude effect, White and Brown (2011) showed how reinforcer magnitude can influence performance even when changed during the retention interval.

As mentioned above, varying reinforcer magnitude is a way in which to manipulate the value of the outcome on DMTS trials. Delaying reinforcement is another way in which to do this. Integrating a delay between the correct response and reinforcement provides an alternative way to manipulate the value of the outcome. A delay to reinforcement has been found to decrease response rate and accuracy (Cox and D'Amato, 1997; Etheredge, 1997; Nakagawa, Etheredge, Foster, Sumpter & Temple, 2004; Weavers, Foster & Temple, 1998).

Etheredge (1997) used hens on a DMTS procedure with variable retention intervals of 0.25 s, 1 s, 2 s, 4 s and 8 s which were used in the first three conditions. In Condition 2, a 6-s delay to reinforcement was introduced on the 2-s retention interval trials. In Conditions 4 to 6 the 1 and 4-s retention intervals were removed and only Condition 5 introduced the 6-s delay to reinforcement on 2-s retention interval trials. The results showed that without a delay to reinforcement there was a decrease in accuracy at longer retention intervals although overall percent correct scores were still relatively high, showing an average of 75% correct at the 8-s retention interval. Conditions 2 and 5 showed a marked reduction in accuracy as a result of the 6-s delay to reinforcement that was introduced on the 2-s retention interval. Accuracy recovered during the conditions

that did not have a delay to reinforcement and the results showed that the decrease in accuracy found on the 2-s retention interval with delay to reinforcement was restricted to that retention interval. These results support delay specific remembering and temporal independence as, at times, the results showed higher accuracy at the 8-s retention interval than at the 2-s and 4-s retention intervals.

Using hens on a DMTS procedure Nakagawa et al (2004) studied the effects of delay to reinforcement. In Conditions 1 and 3 of their first experiment the hens worked on the DMTS procedure under mixed retention intervals of 0.25 s, 2 s and 8 s. Reinforcement was provided immediately for correct responses. In Condition 2, reinforcement was delayed by 6 s on 2-s retention interval trials for correct matching. The results from Condition 1 showed a decrease in accuracy over the longer retention intervals whilst the results from Condition 2 showed a considerable decrease in accuracy for the 2-s retention intervals as a result of the 6-s delay to reinforcement. Accuracy in Condition 3 was found to recover over most intervals with the exception of the 2-s retention interval despite the delay to reinforcement having been removed. Experiment 2 followed the same conditions but with different mixed retention intervals. The retention intervals in Condition 1 and 3 were 0s, 4s, and 16s. In Condition 2 no reinforcement was provided for correct responses on the 0-s and 16-s retention intervals. The results of Condition 1 again showed a decrease in accuracy at longer retention intervals. In Condition 2 the extinction effect from no reinforcement resulted in a greater decrease at the 0-s retention interval. In Condition 3 performance at all retention intervals showed a complete recovery.

The effect of increasing a delay to reinforcement appears to be a decrease in incentive to respond accurately, which is similar to the decrease in incentive

when a small reinforcer is signalled. A longer period of time between responding and receiving reinforcement reduces the value of the reinforcer, just as decreasing the reinforcer size does. Cox and D'Amato (1977) looked at the effects of delay to reinforcement on the incentive to respond accurately. They used cues to signal delay to reinforcement for monkeys working on a two-choice discrimination. On some trials the delay to reinforcement occurred upon completion of the trial while on others a delay preceded the presentation of the stimulus. The aim of the study was to determine whether the decrease in accuracy with added delay to reinforcement was the result of "associative loss or a decline in the incentive value of the reward object caused by the DOR" (Cox & D'Amato, 1977, p. 93). The associative loss hypothesis states that when the discriminative response and its reinforcer are separated by a delay it weakens the association between the response and reinforcer, causing a decline in accuracy. The incentive loss hypothesis states that accuracy decreases because the delay decreases the value of the reinforcer.

On half of the trials the monkeys could choose between the delay to reward and the delay that preceded the stimulus. The delay for both choices was the same in length and was gradually increased until it reached 128 s. The results showed that the animals maintained accurate responding on the trials where the delay preceded the stimulus presentation but performance declined due to the loss of incentive value of the reinforcer.

The findings of these studies further suggest that increasing the delay to reinforcement is equivalent to decreasing the reinforcer size. Accuracy decreases on trials that have delay to reinforcement in much the same way as accuracy decreases on trials where a small reinforcer is signalled. Reducing the incentive

value of the reinforcer may be a reason why response accuracy decreases when a delay to reinforcement is inserted. This is suggested by the above studies. The results found by Etheredge (1997) and Nakagawa et al (2004) provide support for this theory as performance was found to recover in the conditions where delay to reinforcement was removed in conditions after it had been introduced. These studies also add support for delay specific remembering and temporal independence as performance did not always recover at the retention intervals associated with delay to reinforcement.

The current study replicated the procedure used by White and Brown (2011) with signalled delays to reinforcement. The first aim of the study was to see what effect signalling a delay to reinforcement had on matching accuracy. If accuracy decreased on trials where a delay to reinforcement was signalled, it could be argued that signalling a delay to reinforcement has the same effect as signalling a small reinforcer. The second aim was to investigate the effects of reversing the cue for delay to reinforcement during the retention interval, replicating White and Brown (2011) but with delay to reinforcement rather than reinforcer magnitude. By switching the cue partway through the retention interval it may be possible to see a reversal in the signalled delay to reinforcement; if accuracy increases on the trials where the cue was switched from delay to reinforcement to no delay to reinforcement partway through the trial it may suggest a similar finding to the signalled magnitude effect. White and Brown (2011) found that accuracy on these switch trials was higher at the 4-s and 8-s retention interval than at the 1-s and 2-s intervals, providing evidence for temporal independence as the results showed that performance at the longer retention intervals was independent of performance at the shorter retention intervals. If the

current study produces similar findings it may add more evidence to the theory of delay specific remembering and temporal independence.

The procedure used in this study was a variation of the White and Brown (2011) study mentioned above whereby hens were trained on a DMTS procedure with signalled delay to reinforcement. Each trial began with the presentation of the sample stimulus: either a green or red square presented in the centre of a screen. A fixed ratio of five pecks to the square was required in order to remove the sample stimulus and initiate a retention interval of 1, 2, 4 or 8 seconds during which one of two cues was presented on the screen. The cues presented were either a blue square with a cross on it or a yellow square with a vertical line on it: the blue square signalled that for correct responses reinforcement would be delayed by 2.5 s while the yellow square signalled that for correct responses reinforcement would be immediate. Once the retention interval was over the first subsequent peck to the signal square removed the signal and presented the comparison stimuli: both a red and a green square. A response to the comparison stimuli that matched the initial sample resulted in reinforcement. Reinforcement depended on the cue that was signalled during the retention interval. Responses that did not match the sample stimulus resulted in a blackout period. On some trials the cues were switched partway through the trial: the cue would switch from signalling no delay to reinforcement (yellow square) to delayed reinforcement (blue square) 2 s into the retention interval. Due to the switch interval being 2-s long, only the 4-s and 8-s retention interval trials had a cue switch as the 1-s and 2-s retention intervals were too short to insert a switch.

Experiment 1

This experiment had two conditions: matching to sample and delayed matching to sample. Hens were first trained on the matching to sample procedure before moving onto delayed matching to sample to see if increasing the delay interval would cause a decrease in response accuracy. Given the intention was to insert a cue into the delay interval in Experiment 2 the delays used were 1-s, 2-s, 4-s and 8-s.

Method

Subjects

Five experimentally naïve hens, numbered 11.1 – 11.6 served as subjects. They were housed in individual cages in a separate room from the experimental chambers. The hens were maintained at 80-85% of their free feeding weight and were weighed daily. Post feed was delivered each day to ensure the subjects' weights were maintained. Water was always available outside of the experiment chamber, with vitamins and grit provided twice a week.

Apparatus

Experimental sessions were conducted in an experimental chamber constructed of particle board, measuring approximately 53cm high, 42cm wide and 58cm in length. The chamber contained a computer screen surrounded by an infrared screen that detected the location of the birds' pecks. The screen measured approximately 23cm in height and 31cm in width. The screen was situated 27cm above the chamber floor. The screen presented coloured squares approximately 3cm by 3cm onto a black background. Access to wheat was provided by a hopper in an aperture 10cm above the floor. The hopper was illuminated when wheat reinforcers were available and an infrared beam sensed when the hen's head was

in the hopper to feed. The screen, hopper, infrared beam and data recording were all controlled by a PC.

Procedure

Magazine Training and shaping to key peck

Hens were first magazine trained and manually shaped to peck a white square in the centre of the screen. After key pecking was established they were exposed to a fixed ratio (FR 1): one peck to the centre square produced 3-s access to wheat. The hen could receive a maximum of 40 reinforcers over a session. When each hen had received 40 reinforcers per session over three consecutive daily sessions the FR was increased to FR 5. Once each hen received a maximum of 40 reinforcers over a minimum of five consecutive days, matching to sample training was introduced.

Matching to Sample

All birds were then trained on a matching to sample task. Each trial began with the sample stimulus: a randomly selected red or green square was displayed in the centre of the screen and both colours appeared with equal probability. The 5th peck to the sample removed the sample and produced a single square that matched the sample colour and was randomly placed on either the left or right of the screen. A peck to this stimulus resulted in reinforcement. Sessions ended after 2400 s or when 40 reinforcers had been received. The hens continued to perform on the matching to sample training until 40 reinforcers had been received for five consecutive days. At the end of the matching to sample training the maximum number of reinforcers available was reduced to 30 in order to better maintain the bird's weights.

The hens then moved onto the matching to sample procedure. Each trial began with the presentation of a sample stimulus: either a red or a green square in the centre of the screen. The 5th peck to the square removed the sample and produced the comparison stimuli: a red square and a green square: one on the left and one on the right. A peck to the square that matched the sample stimulus resulted in reinforcement. A peck to the square that did not match the sample stimulus resulted in a 3-s blackout. An intertrial interval of 10-s occurred at the end of each trial during which the screen was black with nothing presented on it. The red and green sample stimuli were randomly presented across trials but were both presented equally often.

Delayed Matching to Sample

When the hens were consistently performing at 80 percent correct or above they progressed to delay training on the delayed matching to sample procedure. The procedure followed the same sequence as the matching to sample procedure but with a retention interval inserted between the sample and the comparison stimuli: once the sample had been removed a retention interval occurred before the comparison stimuli were presented. A correct match resulted in reinforcement; an incorrect match resulted in a 3-s blackout. All birds had delay training before moving onto the final delays in the procedure. Delay training began with all four delays (delay A, B, C, & D) equal at 0.25s in length. The retention interval was increased at an equal rate approximately every three sessions, with the exception of the initial retention interval length of 0.25s which lasted seven sessions for birds 11.1 – 11.4. Increasing the retention interval length was dependent on stability of responding; stability was taken to be 80% or more correct. Small retention interval increases were used in order to effectively train the birds at different retention intervals.

Measures

In order to quantify remembering, accuracy was plotted as a function of delay. The measure of discriminative performance was Davison and Tustin (1978) $\log d$. This measure is preferable to percent correct as it is not influenced by any bias towards responding on any particular key. $\log d$ is calculated using the following: $\log d = 0.5 \times \log (\text{red correct} \times \text{green correct} / \text{red incorrect} \times \text{green incorrect})$. However, if any zeros are present in the data, $\log d$ cannot be calculated. In these cases it is necessary to add 0.5 to each response type as suggested by Hautus (1995). The Hautus correction was used for all data irrespective of whether or not there were zero scores. Response bias for red or green samples was calculated using $\log c$, using the equation: $0.5 \times \log (\text{red correct} \times \text{green incorrect} / \text{red incorrect} \times \text{green correct})$.

Results

Matching- to- sample data

Figure 1 shows the discrimination from each session for each hen for matching to sample. Discrimination is shown through $\log d$ values plotted against session number. Bird 11.6 had fewer sessions in this condition as a result of continuing on to the condition later than the other birds, and then reaching criteria in matching to sample quickly. $\log d$ graphs for all birds showed an increase in discrimination after the first several sessions of performing on the matching to sample procedure. $\log d$ increased for all birds after these initial sessions becoming stable at larger than 1.0, indicating that they were discriminating between red and green. This stable pattern of responding continued for the rest of the condition for each bird with no significant decreases.

Log c graphs can be used indicate each of the bird's response bias, if any, to the samples. Data points above the zero line indicate a possible bias towards the red key while data points below the zero line indicate a possible bias towards the green key. Figure 2 shows the log c values for each of the birds. Overall log c was consistent between -1 and 1 for all birds. The data for birds 11.1, 11.2, 11.4, and 11.6 were predominately above the zero line suggesting a bias towards the red key. Bird 11.3 showed no consistent bias toward either key, having almost equal numbers of data points above and below the zero line.

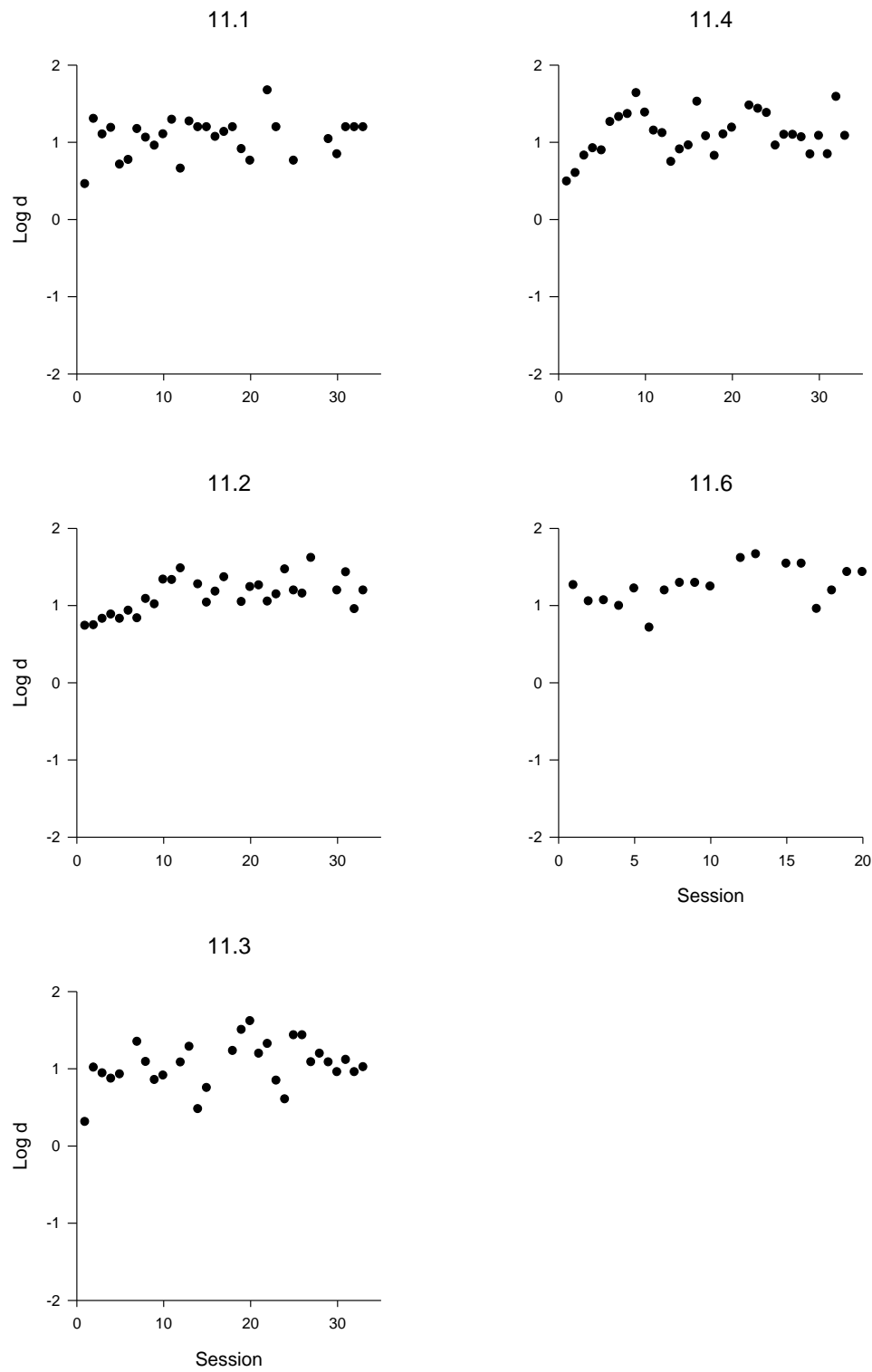


Figure1: $\text{Log } d$ for the matching-to-sample plotted against session number for all birds.

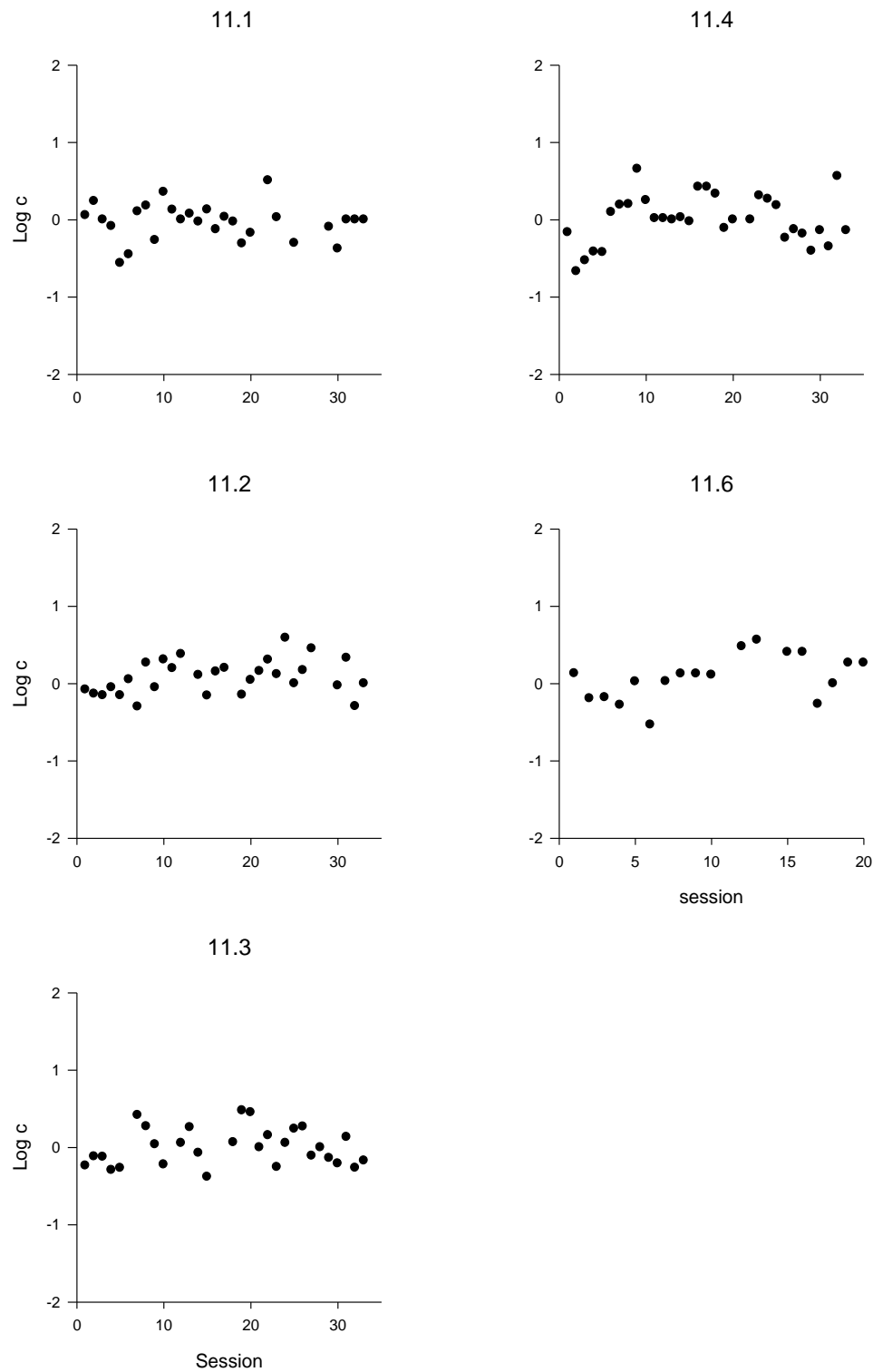


Figure 2: Log c for the matching-to-sample sessions plotted against session number for all birds.

Delayed matching to sample

Figures 3 to 7 show the mean of the $\log d$ (mean discriminability) for delay training calculated for each delay in the DMTS procedure. The four retention intervals used in the procedure (1 s, 2 s, 4 s and 8 s) were labelled delay A, B, C, and D respectively on these graphs. $\log d$ was averaged over all sessions for each interval increment. The data from the first 5 interval increments (0.25 s, 0.5 s, 0.75 s and 0.8 s) are plotted for all four training intervals. When the retention interval reached 1 s the data shown for the three longer training retention intervals are the same but the data point for the 1-s retention interval for training delay A is comprised of an average over the first 8 sessions after reaching the 1-s retention interval. The data plotted from 1-s to 2-s for Delay B (2 s) are from potential 2 s delay trials only (approximately 3 sessions per increment). The data point for delay B at 2-s is an average over the first 8 sessions after reaching the 2-s retention interval. Delays C (4 s) and D (8 s) continued to have $\log d$ plotted for each increment until both delay C and D were at 3.75-s at which time the intervals were increased to 4-s for delay C and 8-s for delay D. Mean $\log d$ for each increment up until 3.75-s are based on approximately 3 sessions per increment. The final retention intervals of 4-s for delay C and 8-s for delay D were comprised of mean $\log d$ for the first 8 sessions after reaching 4 s and 8 s respectively.

Figure 8 shows the mean $\log d$ for each bird for retention intervals 1 s, 2 s, 4 s and 8 s. Each data point shows the mean $\log d$ for each retention interval from the last 6 sessions of the DMTS procedure. The results of the DMTS show that accuracy did not necessarily decrease as the retention interval increased. While there was an initial drop off in accuracy from 0-s interval (matching to sample)

shown in Figure 1, when the 1-s and 2-s intervals were introduced, accuracy did not show any consistent trends at the longer retention intervals.

Overall, the birds showed no consistent trends in discrimination at each retention interval: discrimination did not necessarily decrease at the longer intervals but rather fluctuated across intervals. Discrimination was found to be highest between the 2-s and 4-s intervals across all birds. Discrimination across all birds showed increased and decreased variability as the retention intervals increased, showing no specific trend or pattern.

11.1

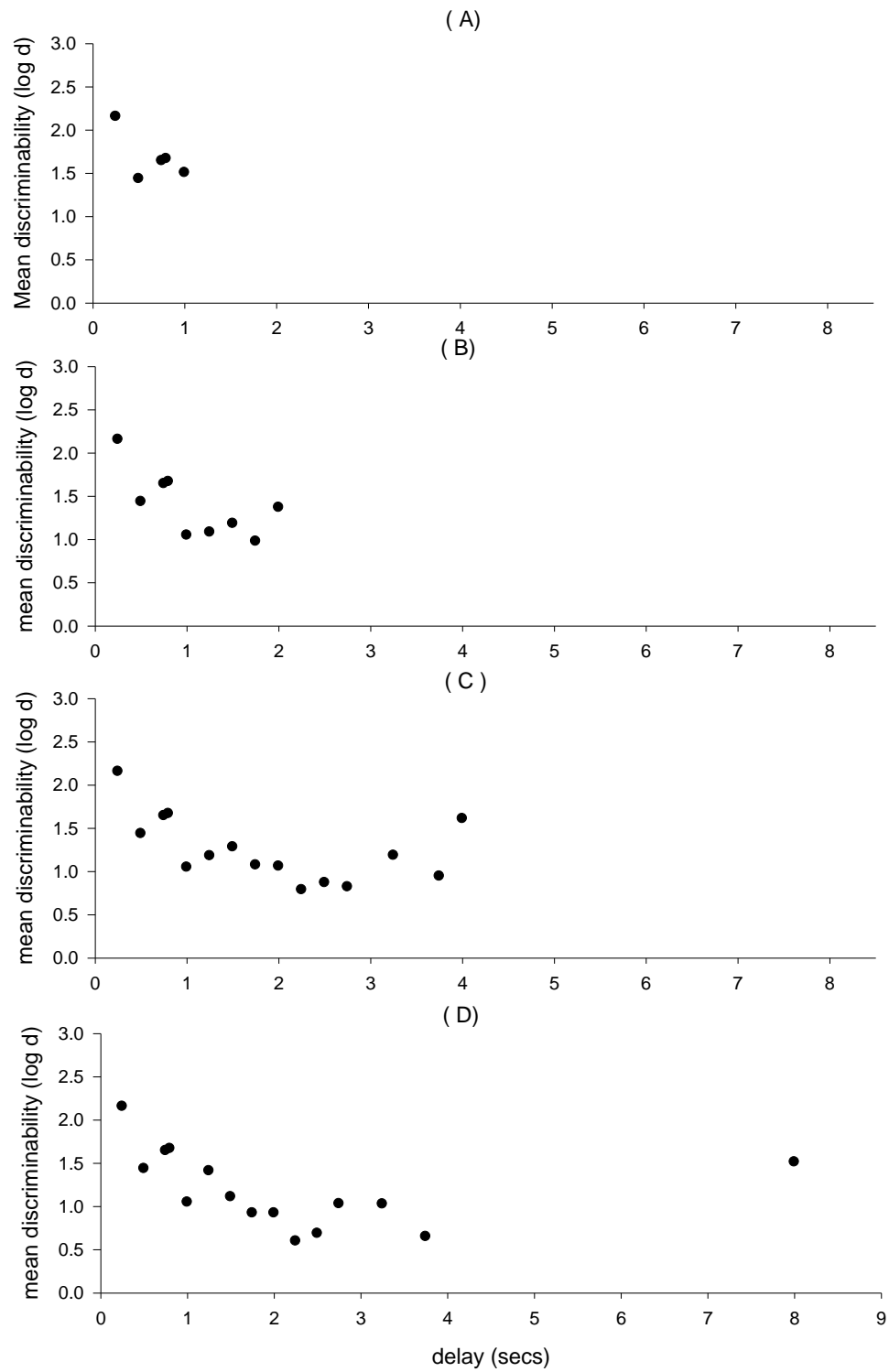


Figure 3: Mean $\log d$ as a measure of mean discriminability for delay training: (A)

1 s delay, (B) 2 s delay, (C) 4 s delay, and (D) 8 s delay for bird 11.1.

11.2

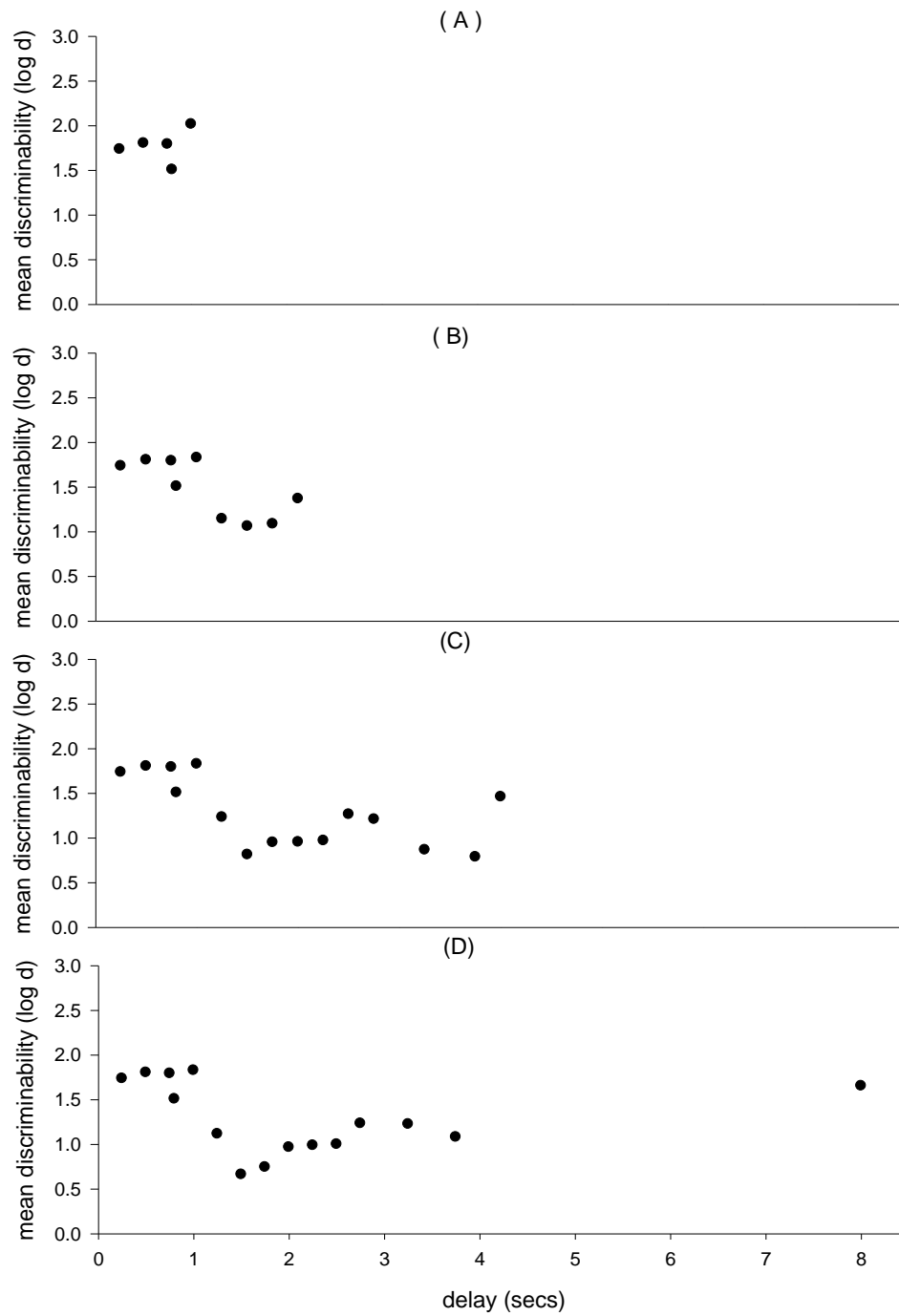


Figure 4. Mean $\log d$ as a measure of mean discriminability for delay training: (A) 1 s delay, (B) 2 s delay, (C) 4 s delay, and (D) 8 s delay for bird 11.2.

11.3

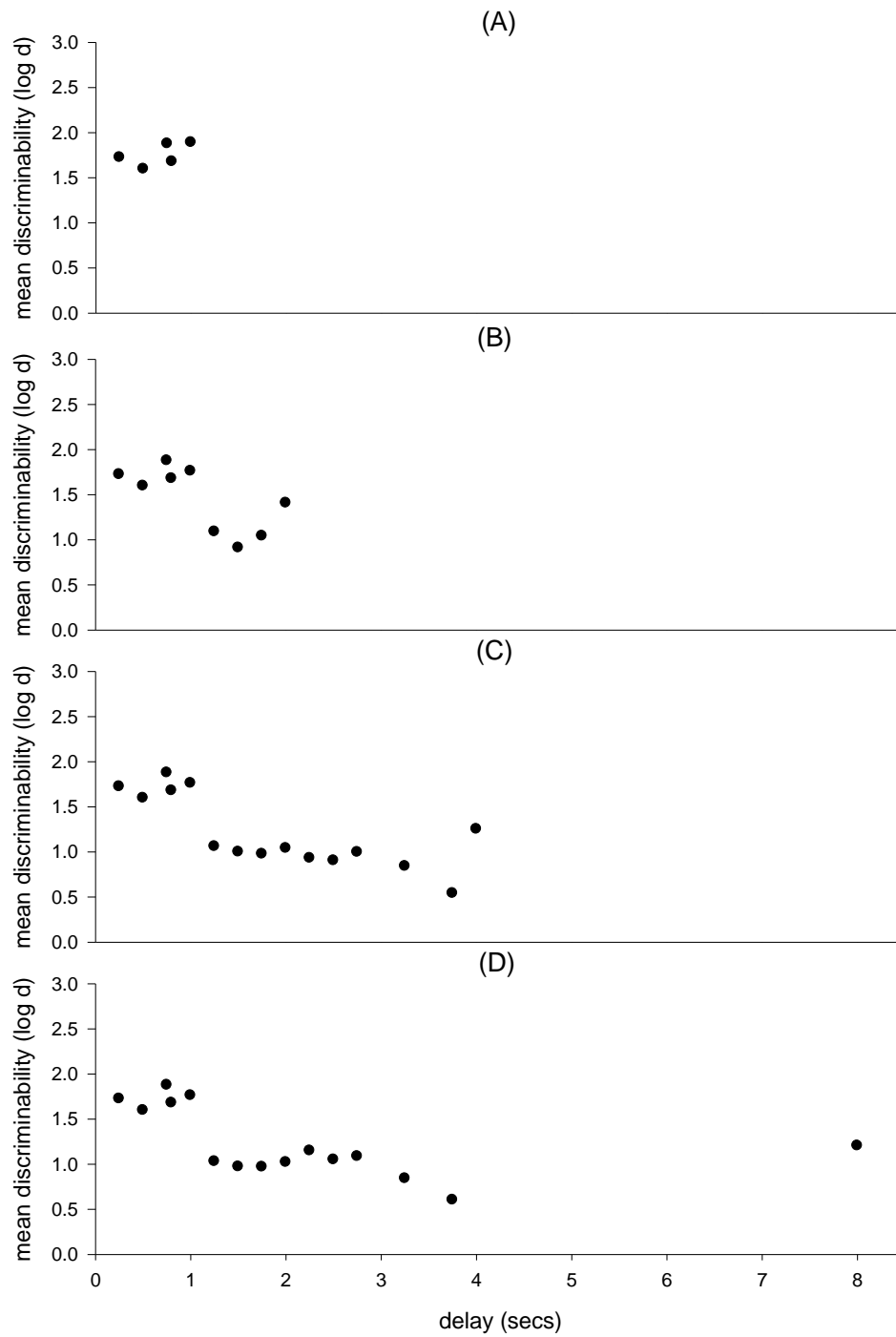


Figure 5: Mean $\log d$ as a measure of mean discriminability for delay training:

(A) 1 s delay, (B) 2 s delay, (C) 4 s delay, and (D) 8 s delay for bird 11.3.

11.4

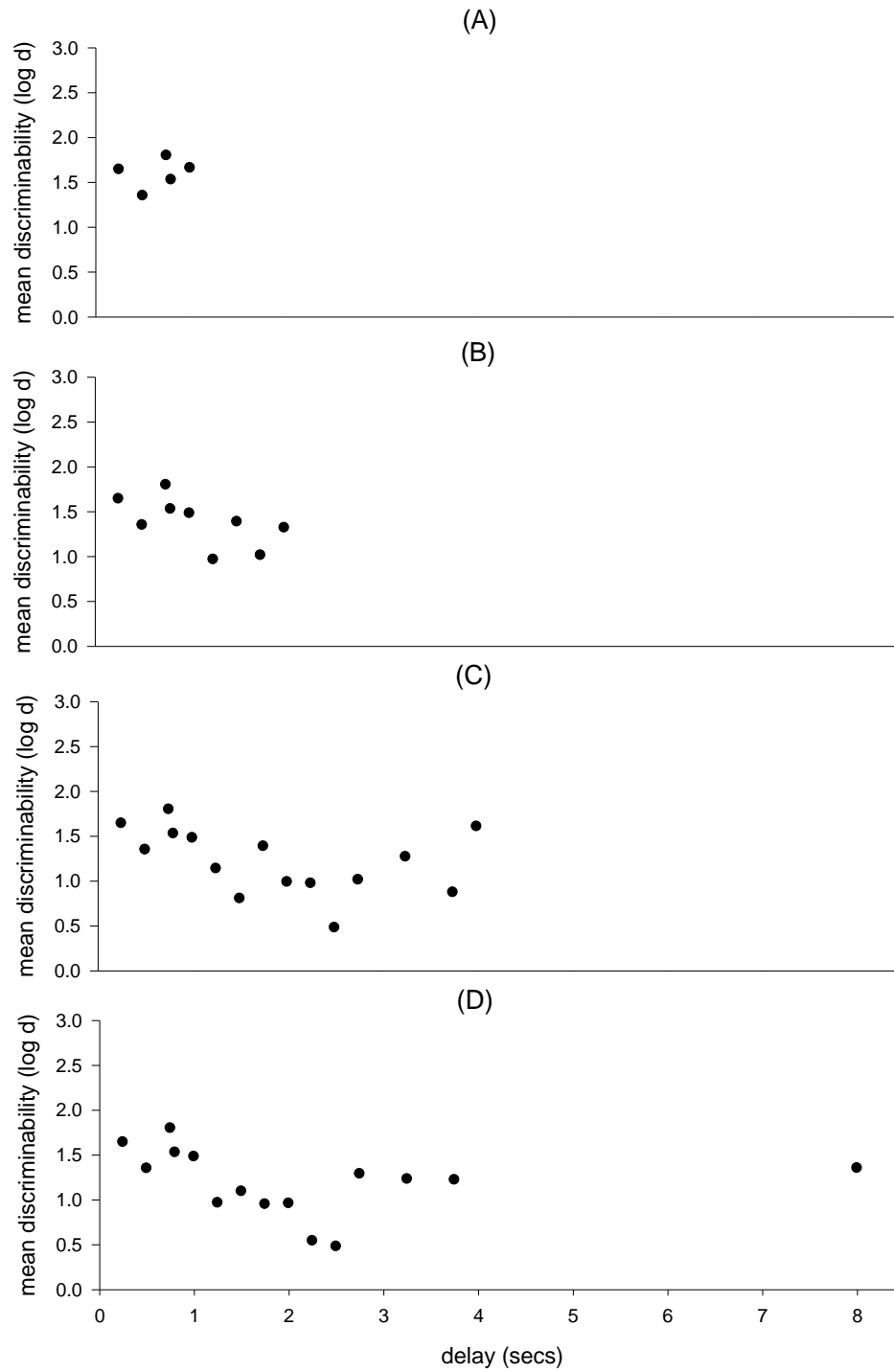


Figure 6: Mean $\log d$ as a measure of mean discriminability for delay training: (A) 1 s delay, (B) 2 s delay, (C) 4 s delay and (D) 8 s delay for bird 11.4.

11.6

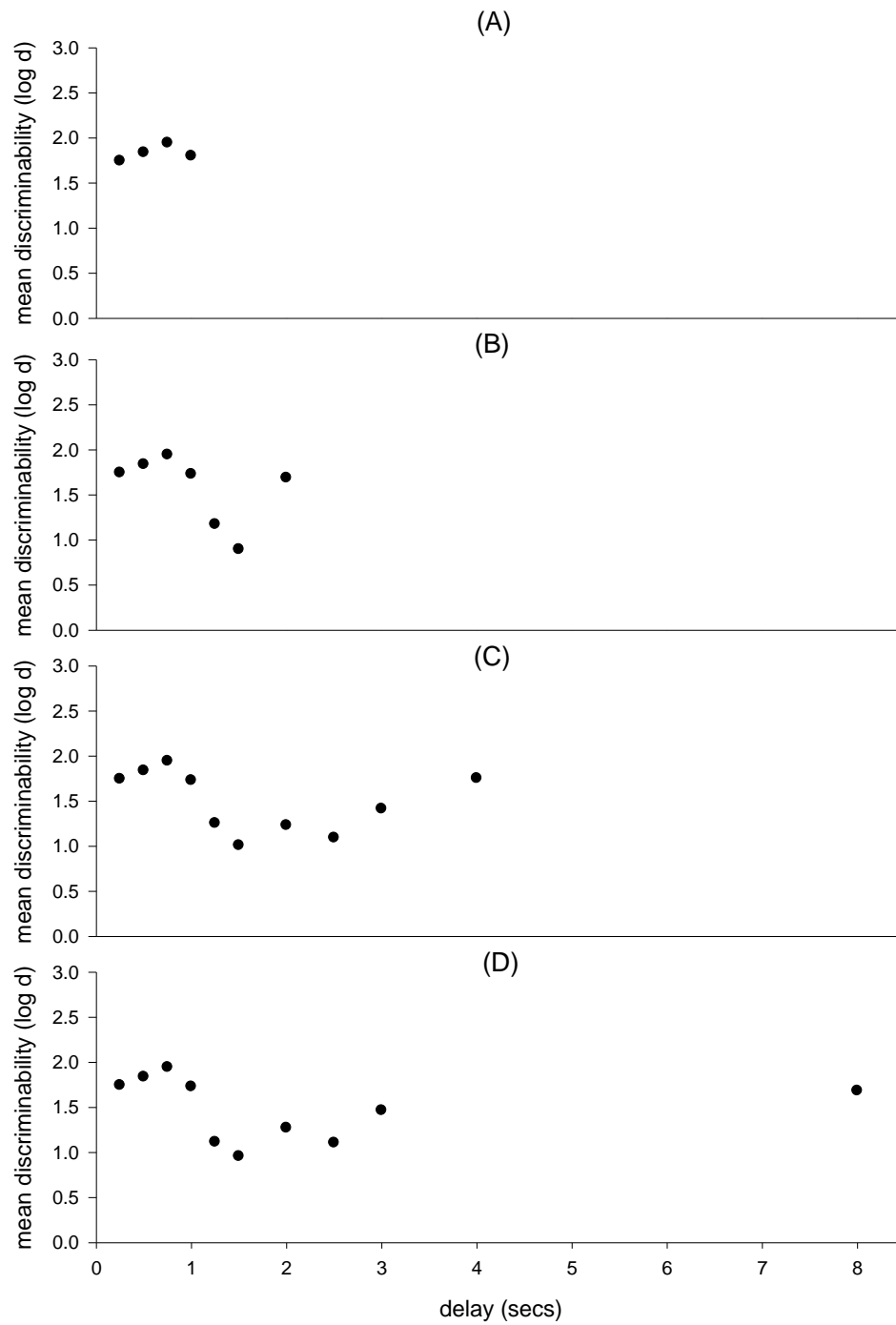


Figure 7: Mean $\log d$ as a measure of mean discriminability for delay training: (A)

1 s delay, (B) 2 s delay, (C) 4 s delay and (D) 8 s delay for bird 11.6.

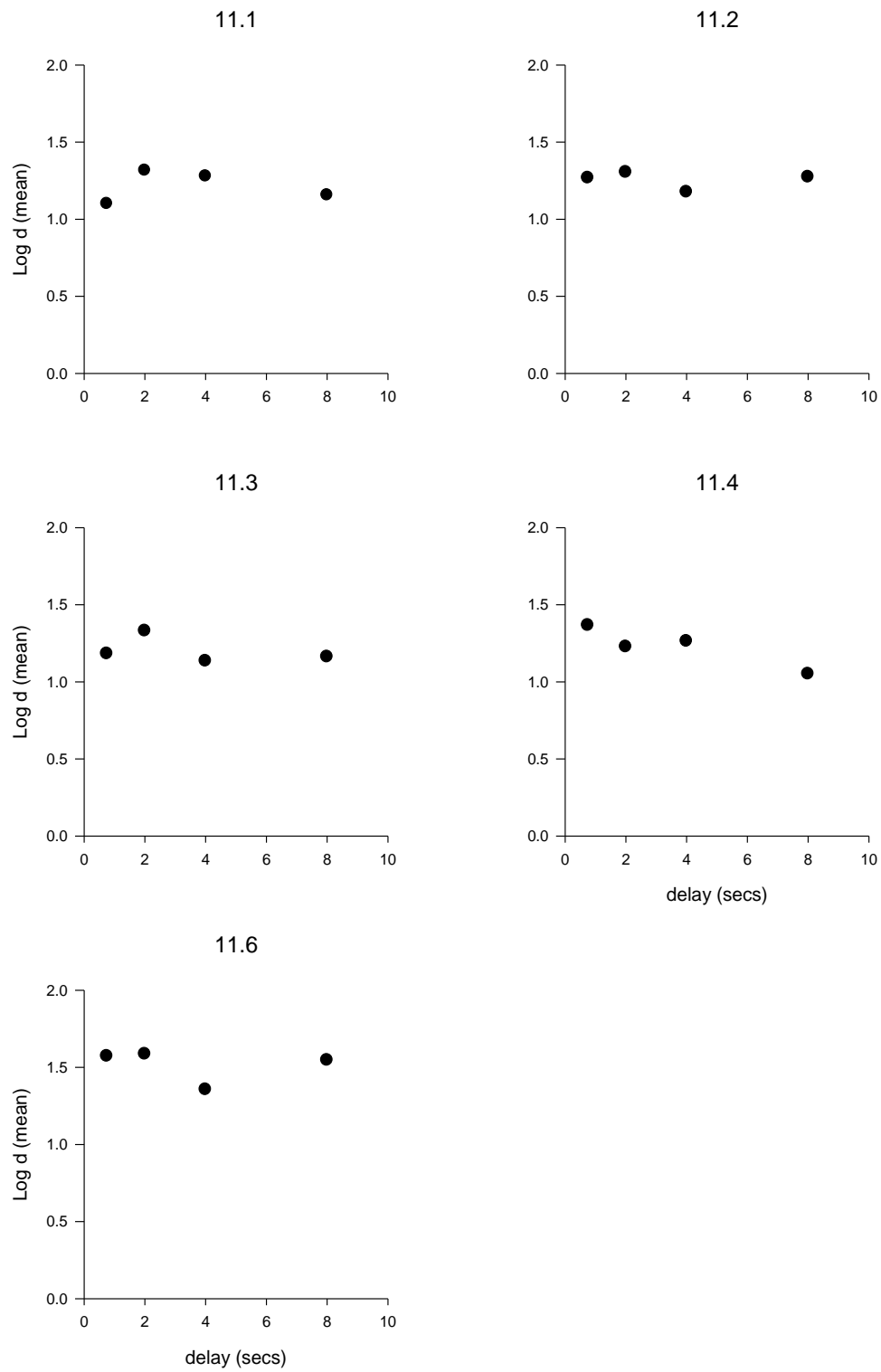


Figure 8: Mean discriminability for the 1 s, 2 s, 4 s and 8 s delay for each bird for the last 6 sessions.

Discussion

Common findings in DMTS procedures show a decrease in response accuracy as retention intervals increase. These results were expected in the current condition: higher accuracy at shorter intervals and lower accuracy at the longer intervals. However, the results obtained differ from those that were expected. Matching accuracy across all birds showed little difference across the different retention intervals: accuracy was just as high at the longer intervals as it was at the shorter intervals. While these results contradict the usual DMTS finding, they do however suggest that temporal independence occurred (White in press). This theory states that performance at one retention interval may be independent of performance at another retention interval, be it a smaller or larger interval. The consistently high accuracy across all retention intervals suggests that this occurred in the current study. The training method used to train the hens in the DMTS procedure may be responsible.

Training for the delayed matching to sample was carried out using small increments to slowly introduce the retention intervals. White (in press) states that “in order to maintain high accuracy at short delays and minimise the development of response bias at long delays, a successful strategy is to gradually lengthen the delays as training progresses” (p. 11). Adopting this approach in the current study meant that the birds worked on the procedure with very small retention intervals and with small increases in the length of the interval. Odey (1991) trained hens on a DMTS procedure using very gradual increases in retention interval length starting from 0.01 s until 12 s. Stability data was taken at 0.5 s, 1 s, 2 s, 4 s, 8 s and 12 s. The results showed that accuracy for the 12- s retention interval remained above 75%, showing no trend in discrimination as is commonly found in DMTS procedures. Odey (1991) postulated that the method of retention interval

training using the gradual increases in retention intervals was responsible for the maintained performance at long intervals observed after training. The high rate of accuracy found in the current results for the longer intervals is similar to that found in Odey (1991). Accuracy for the 8-s retention interval consistently remained between 60 and 80% across all birds. Odey (1991) also reported that discrimination was initially high, with discrimination decrement being slow. This is true of the current study as well, with little or no decrement occurring over the longer intervals. The results from both Odey (1991) and the current study suggest that the gradual increasing of the retention intervals may have contributed to the maintained performance found in both studies.

The gradual increases in retention interval length for both studies meant that the birds were receiving a lot of practice on the task. In the current study, the birds worked for approximately 3 sessions on each increment, providing them with a lot of exposure to the task. Breen (1987) stated that “if practice enhances performance, delay curves of performance at various delays would be expected to show improvements in discrimination with training at larger delay interval durations” (p. 12).

While the present study did not train at the set longer retention intervals of 4-s and 8-s, discrimination did improve with the longer retention interval durations and may be explained by the findings of Sargisson and White (2001). They used pigeons on a DMTS procedure. Their pigeons were trained at different retention intervals of 0, 2, 4, or 6 s and were then tested using a range of intervals. Results showed that the intervals at which the birds were trained produced the highest the accuracy: birds trained at 0 s peaked in accuracy at the 0-s interval, while birds trained at the 2-s interval peaked in accuracy at 2 s and so on.

Accuracy was found to increase as the retention interval increased, particularly for the longer intervals of 4 s and 6 s. When the retention interval was decreased to 0 s the birds trained at 2, 4 and 6 s decreased in accuracy after the first session; accuracy only began to increase at 0 s after retraining at 0 s.

The finding for the current study shows that accuracy across birds commonly peaked between 2 s and 4 s, often increased at the higher intervals and was lower at the shorter intervals. These results when plotted did not show a forgetting function as is commonly found in the DMTS procedure. Sargisson and White (2001) argue that when trained at retention intervals higher than 0-s, the function found appears to be more of a generalisation gradient than a forgetting function. This is due to the peaks in accuracy occurring at the intervals at which training took place, and increasing at longer intervals. This appears to be true of the current study. A reason for this occurring in the current study may lie in the retention interval training; the final increase in interval increment for the 4-s and 8-s retention intervals was 3.75 s, after which the intervals were increased straight to 4 s and 8 s. The accuracy for the 4-s and 8-s intervals commonly peaked between 2 s and 4 s across all birds and showed no significant decreases at the 8-s retention interval indicating a possible generalisation to the retention intervals associated with the last training interval.

In summary, the results of the DMTS procedure may have been a combination of factors that can be attributed to the retention interval training. The incremental increases in retention interval length allowed the birds a lot of practice at each increment resulting in maintained high performance. However, generalisation may have occurred for the 4-s and 8-s intervals due to the length of the final increment, accounting for the generalisation gradient and lack of

forgetting function. Overall, these factors appear to have resulted in temporal independence, which together with the possible retention interval generalisation suggest that delay specific remembering occurred as a result of the training method. This would explain the high accuracy across all intervals.

Experiment 2

This experiment used the delayed matching to sample procedure described earlier, with cues during the retention interval to signal whether reinforcement would be delayed or immediate. The aim was to see if accuracy on delayed to reinforcement trials would decrease and if accuracy would increase on the no-delay-to-reinforcement trials.

Method

Subjects

The same five birds that were used in Experiment 1 were used in Experiment 2.

Apparatus

The same apparatus used in Experiment 1 was used in Experiment 2.

Procedure

During this condition, there were two types of trials the hens could be presented with: delay to reinforcement trials and no delay to reinforcement trials. On delayed reinforcement trials the hen was presented with a sample stimulus, a randomly allocated red or green square. The hen pecked the sample five times, which extinguished the (red or green) sample square and initiated a randomly assigned retention interval of 1, 2, 4 or 8 s. All retention intervals occurred with equal probability. During the retention interval a blue square (the cue) was shown on the centre of the screen, approximately 3 cm by 3 cm. The cue remained in place for the duration of the retention interval and the first subsequent peck to the

cue extinguished it and produced the comparison stimuli: a red square and a green square. The hen was then required to make a choice between the two squares. Following a correct choice a delay of 2.5 s was initiated, (during which nothing was presented on the screen) before 3-s access to wheat was provided. An incorrect response resulted in a 3-s blackout. An intertrial interval of 10 s occurred at the end of each trial regardless of the outcome during which nothing the screen was black with nothing presented on it.

On no-delay-to reinforcement trials the procedure followed the same sequence of events as on the delay-to-reinforcement trials except that during the retention interval the cue presented was a yellow square shown on the centre of the screen. Once the retention interval ended the hen made a choice between the red and green squares and was immediately reinforced for correct choices with 3 s access to wheat. Incorrect responses resulted in a 3-s blackout. A 2.5 s blackout occurred before an intertrial interval of 10 s occurred at the end of every trial independent of the outcome.

The signalling trials in the DMTS procedure ran daily with sessions lasting a maximum of 2400-s. Sessions could terminate once 2400-s had been reached or when 30 reinforcements had been received.

Results

Figure 9 shows the mean $\log d$ over the last 12 sessions for each cue at each retention interval. The circles indicate the mean $\log d$ at each retention interval for the cue that signalled a delay to reinforcement. The squares show the mean $\log d$ at each retention interval for the cue that signalled no delay to reinforcement. Across all birds there was no consistent difference in $\log d$ values for the different cues, i.e., the birds performed similarly regardless of the cue

colour. Discrimination was similar over all the retention intervals, showing no consistent increases or decreases over retention intervals.

Log c for all birds for each cue at each retention interval for the last 12 sessions is shown in Figure 10. Log c was predominately between 0 and 1.0 and consistently above the zero line for all birds, indicating response biases towards the red key. The bias for 11.1, 11.3 and 11.4 was small, with data points just above the zero line, while birds 11.2 and 11.6 show larger biases, with data points further above the zero line.

Figure 11 shows the mean percent correct for each cue at each retention interval for all hens over the last 12 sessions. Percent correct can be prone to a bias effect but provides another way to present responding. Percent correct was variable across birds: for birds 11.1 and 11.3 it was predominately between 60 and 80% regardless of the cue or retention interval. Percent correct was more variable over cues for 11.2 and 11.4; the biggest difference in percent correct for 11.2 was for the 2-s delay where there was a higher percent correct for the cue for no delay to reinforcement than for the delay to reinforcement cue. The biggest difference in accuracy for 11.4 occurred at the 4-s retention interval with the percent correct for the cue for no delay to reinforcement being higher than that for the delay to reinforcement cue. Percent correct for 11.6 was consistently around 80%, and there were no consistent differences over retention intervals or cues. Overall, across all birds there was no consistent difference in percent correct for the different cues or retention intervals.

Both log d for the delayed matching to sample procedure from Experiment 1 and from the present experiment for all birds across all retention intervals are shown in Figure 12. The mean of the log d for Experiment 1 are

denoted by the diamonds, mean $\log d$ values for the cue that signalled the delay to reinforcement are shown by the circles and the mean of the $\log d$ for the cue that signalled the no delay to reinforcement is shown by the squares. Mean $\log d$ for Experiment 1 were based on the last 6 sessions of the procedure, while the mean $\log d$ values for the signalled delay to reinforcement were based on the last 12 sessions of the procedure. In the signalled delayed to reinforcement condition half the trials were delay to reinforcement trials and the other half no delay to reinforcement trials, this required twice the number of sessions to be used to give an equal number of trials as was used to calculate $\log d$ in Experiment 1.

Comparing the mean $\log d$ values from Experiment 1 with the mean $\log d$ values of the signalled delay to reinforcement indicated that there was no consistent difference between $\log d$ across the different cues and at the different retention intervals. All mean $\log d$ values for both Experiment 1 and signalled delay to reinforcement were consistently between 1 and 2.

Figure 13 shows the total number of pecks the hens made to each of the cues during the retention interval for the last 6 sessions. The number of pecks to the cues ranged between 10 and 80, with no consistent differences in the number of pecks to either cue: the number of pecks to each cue was similar across birds.

Figure 14 shows the programmed retention intervals against the obtained retention intervals for each cue across all retention intervals for each bird. The circles indicate the obtained retention interval lengths for the delay to reinforcement trials while the squares show the obtained retention interval lengths for the no delay to reinforcement trials. The figure indicates that there was often a delay after the end of the programmed retention interval before the birds responded to terminate the interval. Thus the obtained retention intervals were

longer than the programmed retention intervals. Overall, there was no consistent difference between the obtained retention intervals for the cues. The 8-s retention interval produced the largest differences between programmed and obtained delay interval lengths for all birds, with the exception of 11.2, this bird had the largest difference at the 4-s retention interval for delay to reinforcement.

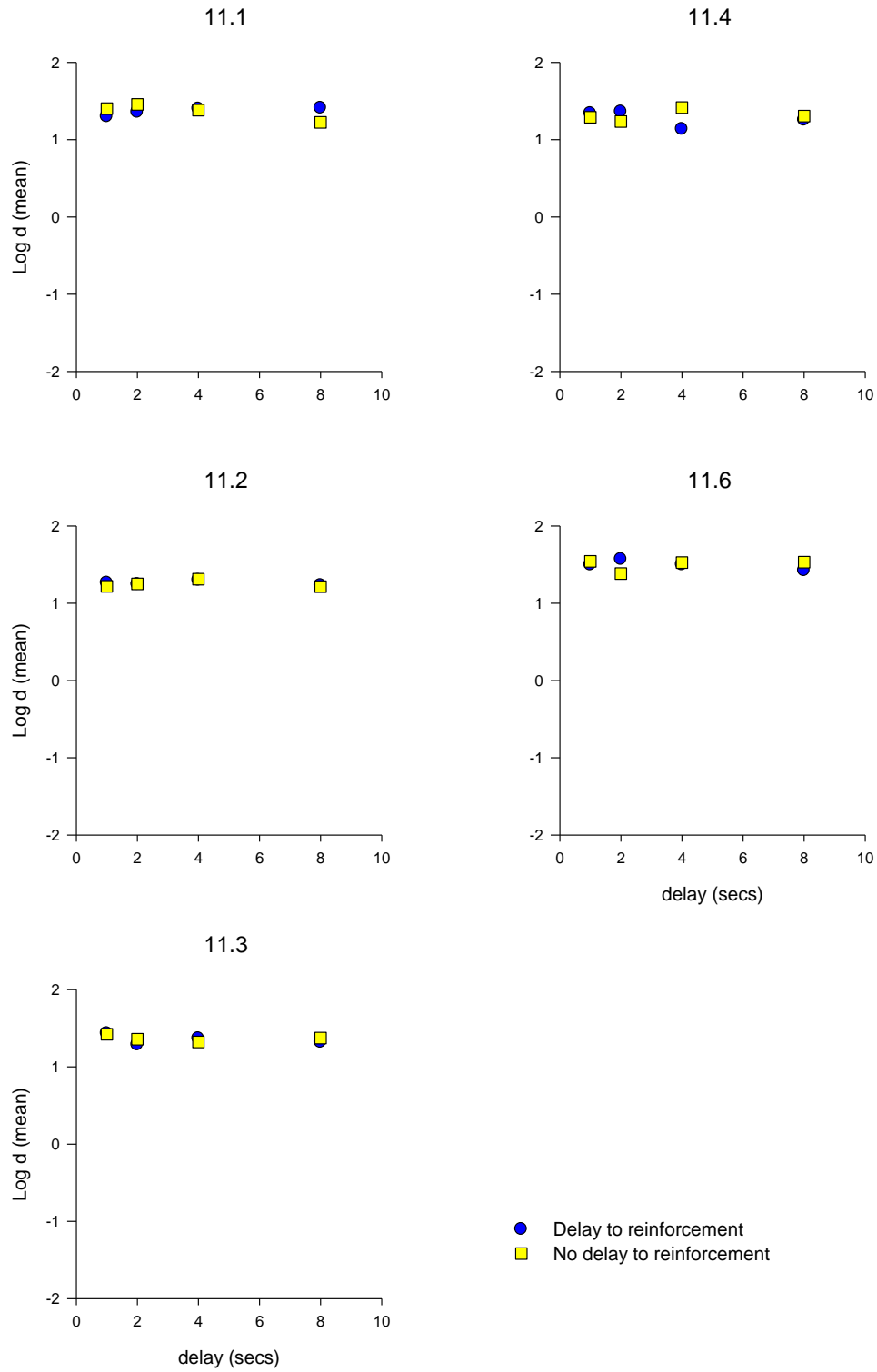


Figure 9: Log d as a measure of discrimination for delay to reinforcement and no delay to reinforcement for each retention interval for all birds from the last 12 sessions.

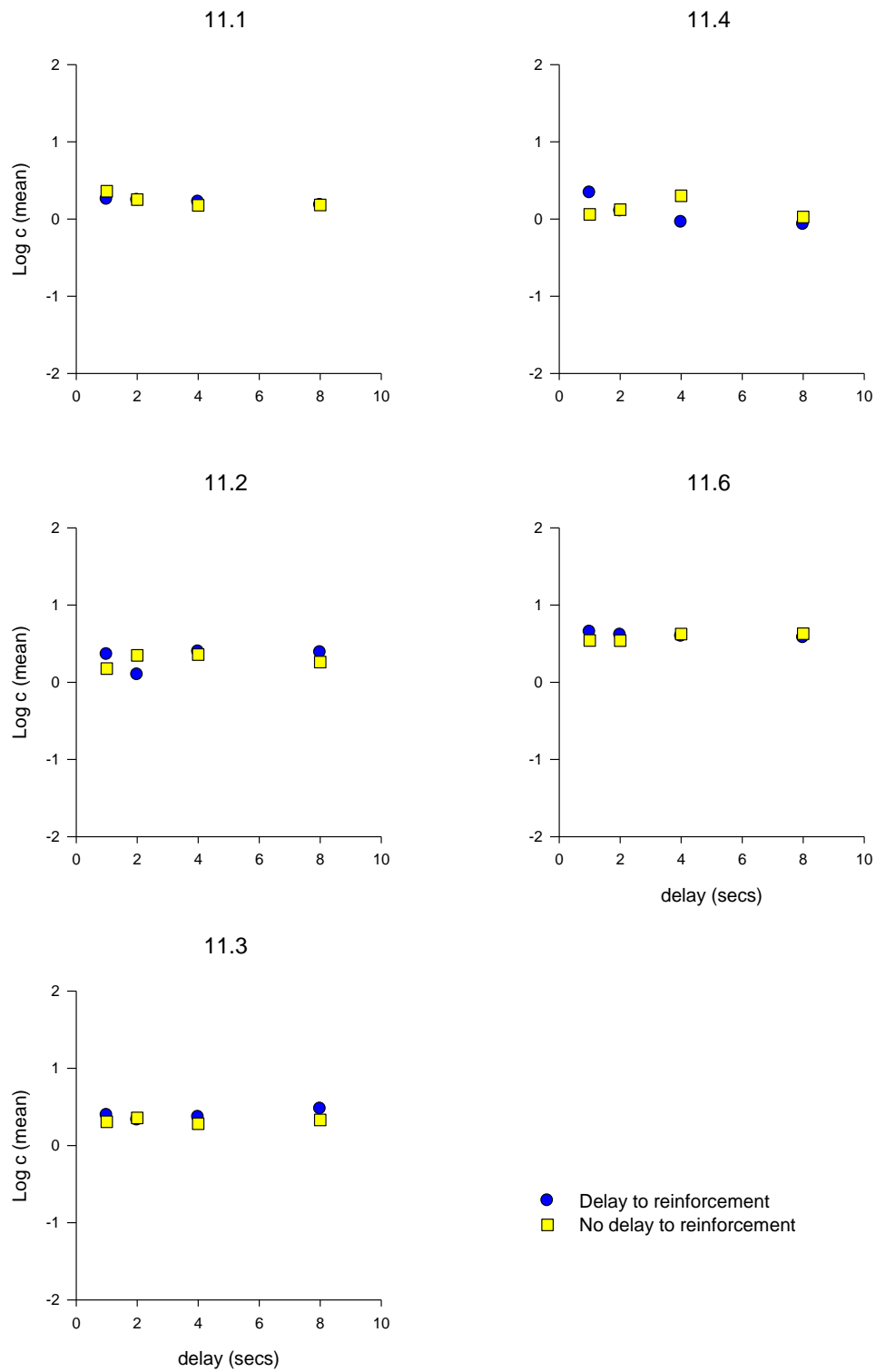


Figure 10: Log c as a measure of response bias for delay to reinforcement and no delay to reinforcement for each retention interval for all birds from the last 12 sessions.

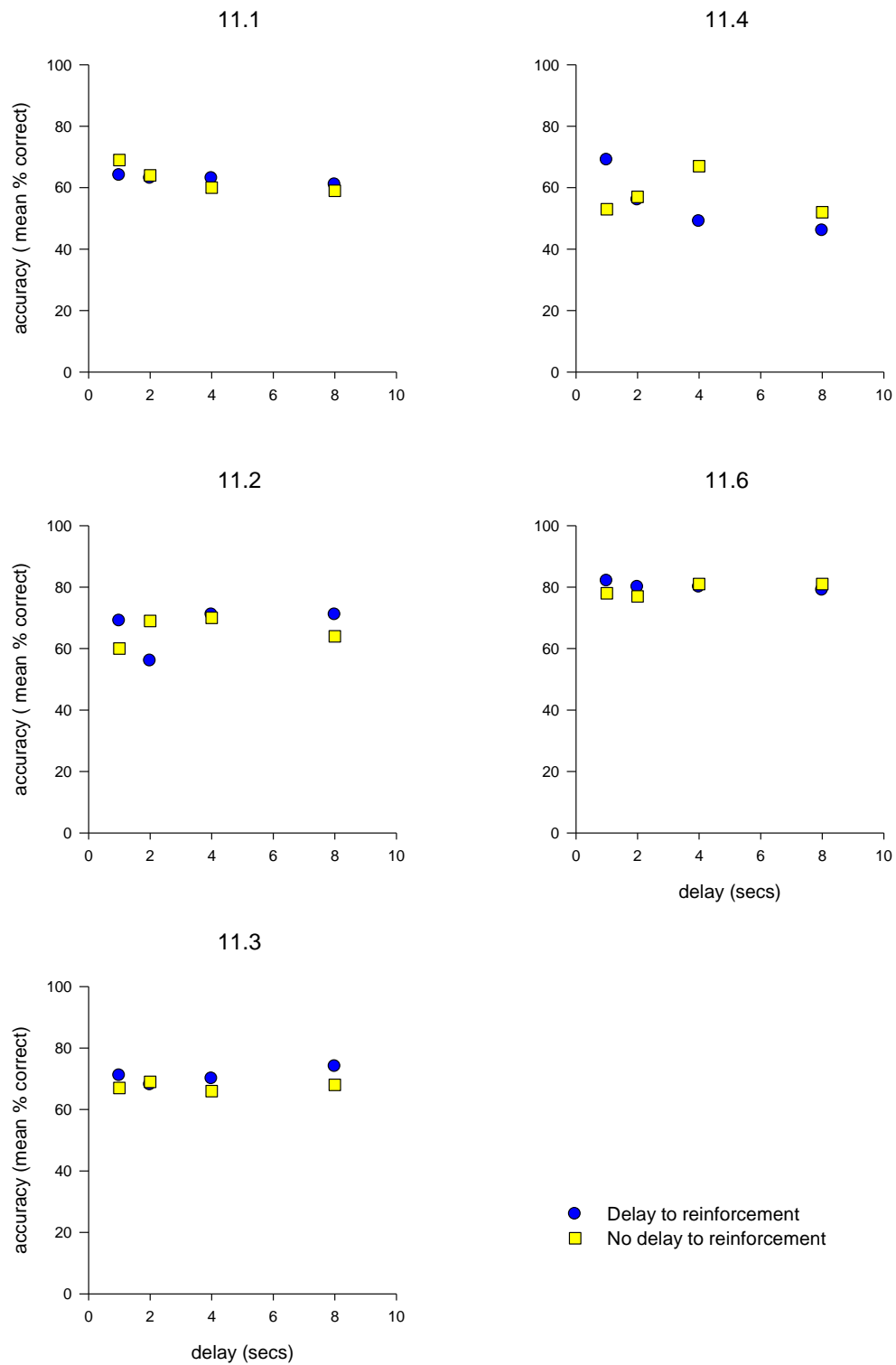


Figure 11: Percent correct as a measure of matching accuracy for delay to reinforcement and no delay to reinforcement for each retention interval for all birds from the last 12 sessions.

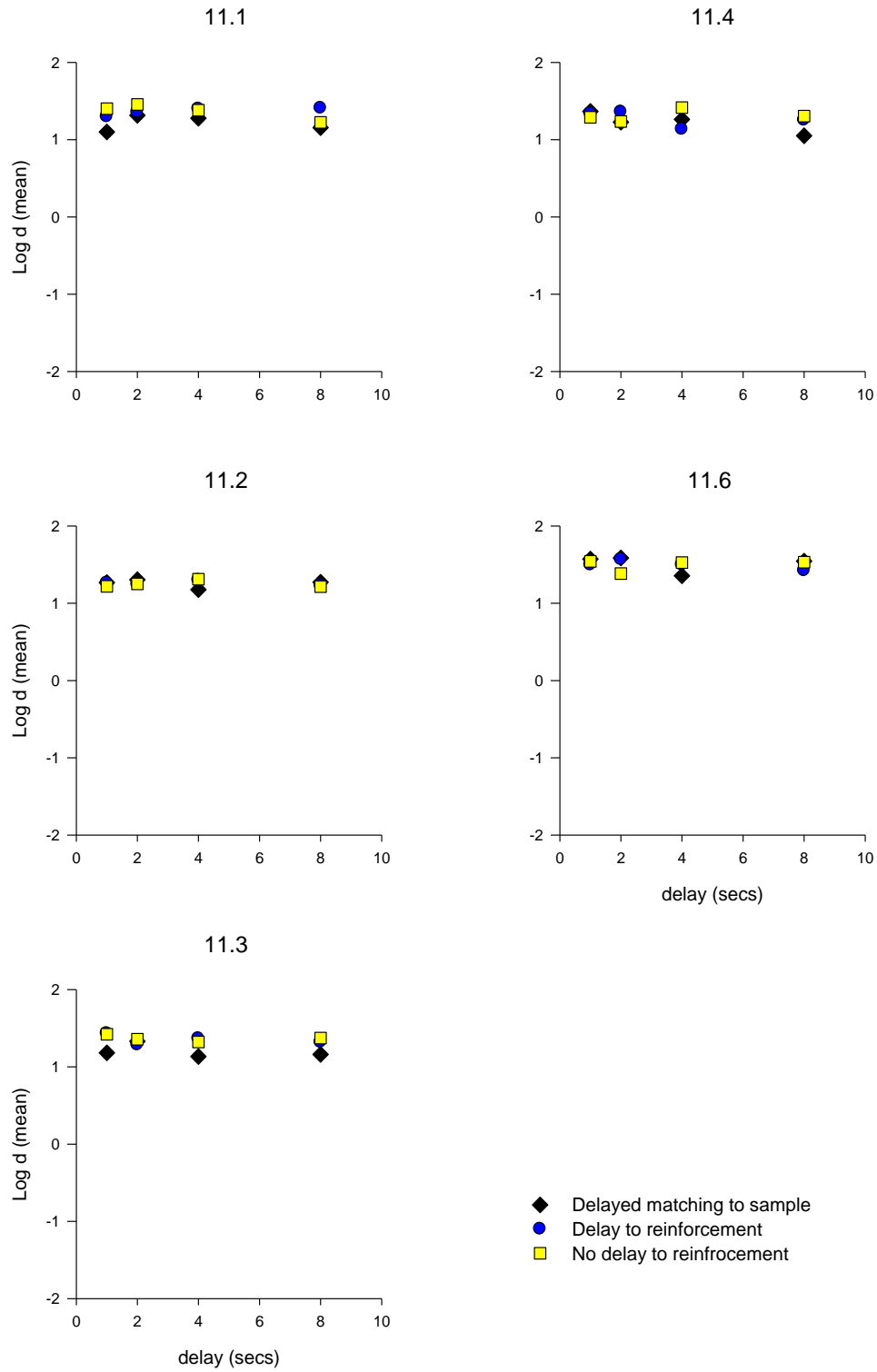


Figure 12: Mean log d for delayed matching to sample (baseline) from the last 6 sessions against mean log d for delay to reinforcement and no delay to reinforcement from the last 12 sessions across all retention intervals for all birds.

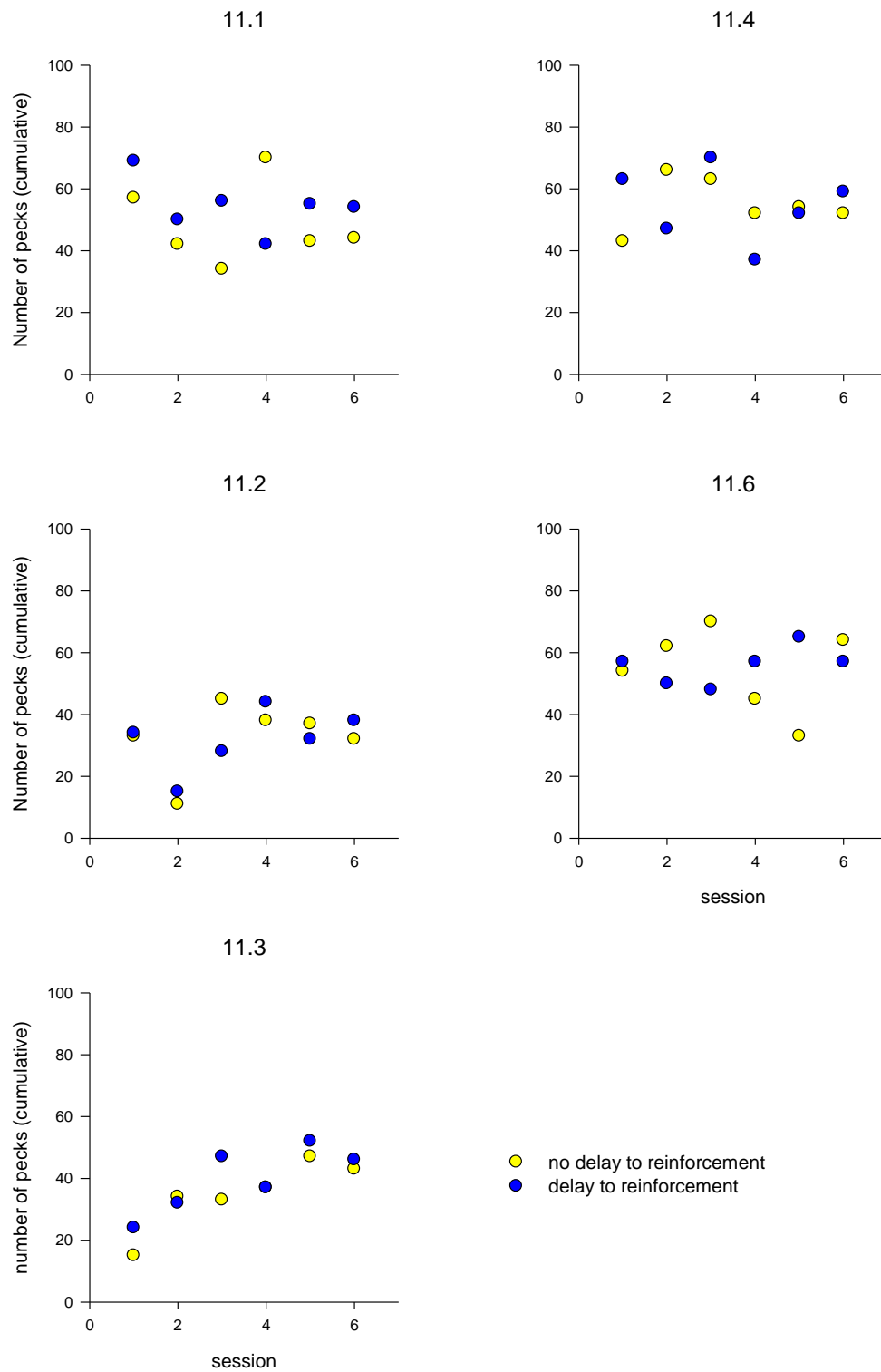


Figure 13: Total number of pecks to each cue across all retention intervals from the last 6 sessions of delay to reinforcement and no delay to reinforcement for all birds.

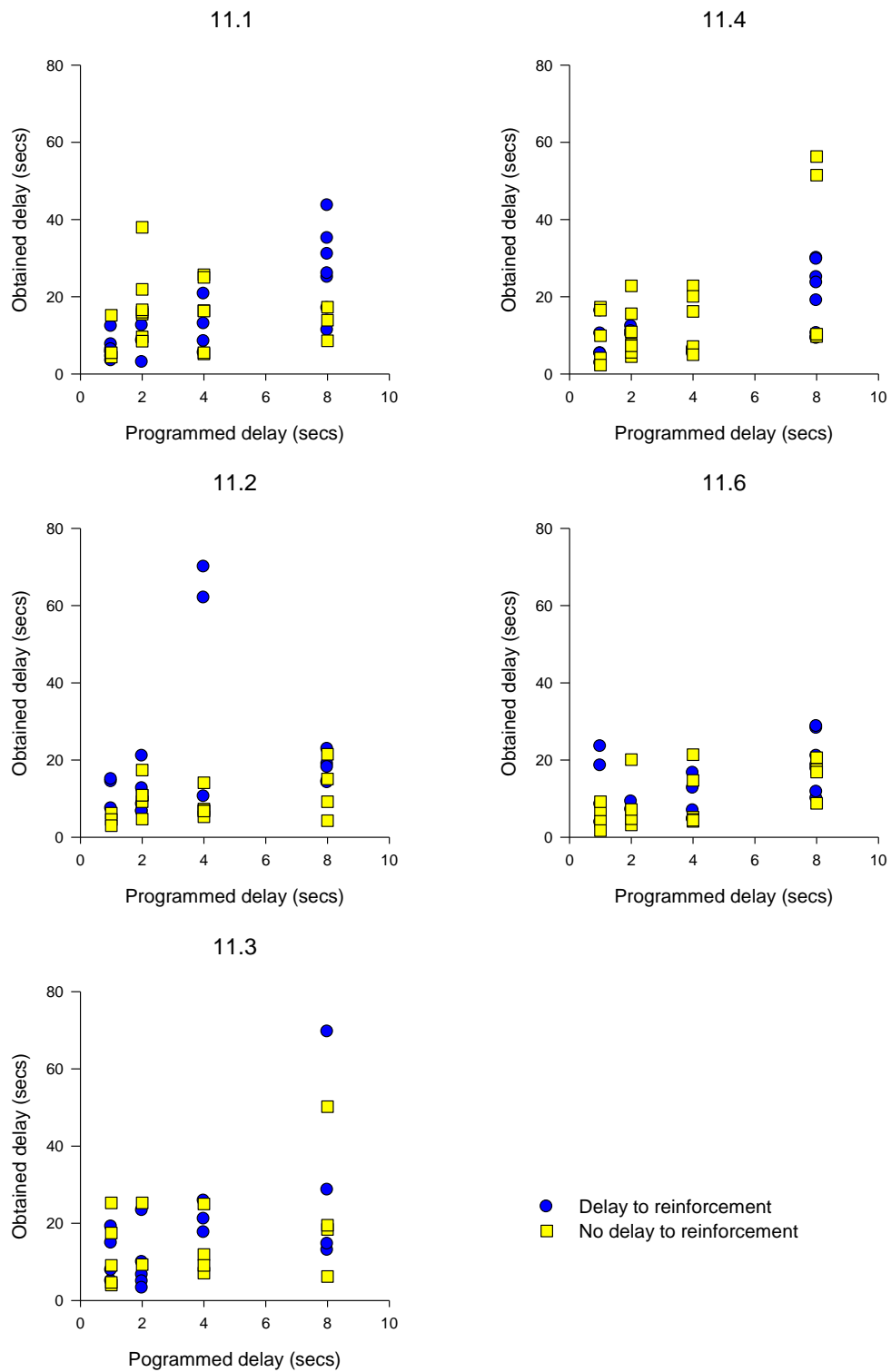


Figure 14: Programmed retention interval lengths against the obtained retention interval lengths for each bird for delay to reinforcement and no delay to reinforcement from a single session.

Discussion

The overall findings show that inserting the cues into the retention interval during the DMTS procedure did not result in any significant change in differential accuracy: response accuracy appeared to be the same for both delay to reinforcement and no delay to reinforcement.

As previously discussed, White and Brown (2011) found that signalling the magnitude of the upcoming reinforcer produced different behaviour: signalling a large reinforcer increased matching to sample accuracy whilst signalling a smaller reinforcer decreased matching accuracy. White and Brown (2011) referred to this as the signalled magnitude effect, arguing that signalling a larger reinforcer over a smaller reinforcer produced better accuracy as a result of increased incentive to respond on trials that provided a larger reinforcer. On the basis of this it was hypothesised that signalling a delay to reinforcement would act in a similar way to signalling a smaller reinforcer. It was expected that accuracy would decrease on the blue cue trials (delay to reinforcement) and increase on yellow cue trials (no delay to reinforcement). It was also hypothesised that accuracy would decrease at the longer retention intervals and be the least accurate at these intervals for the delay to reinforcement (blue cue) trials. The findings were, however, that there were no consistent differences in matching accuracy at all of the retention intervals for both the delayed to reinforcement trials and the no delay to reinforcement trials.

That delay to reinforcement had no effect on behaviour was unexpected, given that others found that delaying reinforcement affects behaviour. The birds appear to have failed either to learn to discriminate between the different cues or it could be that what the cues signalled did not lead to differential responding. A

possible reason for this is that the birds had no prior training with signalling cues. After completing the DMTS procedure in Experiment 1 the birds immediately continued onto delayed matching with cues, which perhaps should only have occurred after some initial training with the cues.

Another possible reason for the lack of discrimination is that the delay to reinforcement was too short: the delay was set at 2.5-s on the delay to reinforcement trials. Etheredge (1997) used variable delay to reinforcement lengths with the longest delay being 8-s. He found that accuracy decreased on the conditions where the delay to reinforcement was introduced but recovered in the conditions where the delay to reinforcement was removed, indicating that the delay affected response accuracy. Increasing this delay potentially could have had more of an effect. The variable accuracy in data found at each retention interval (higher accuracy at the longer retention intervals) may have occurred as a result of the training with delayed matching to sample which showed a consistently high rate of accuracy across retention intervals. Another possibility for the lack of discrimination could be the species: the delay effect may not be as effectively demonstrated by hens as it is with other species such as pigeons and monkeys. Etheredge (1997) demonstrated an effect of delay to reinforcement using hens, however, his study neither provided a cue to signal the delay to reinforcement nor did it make use of the training method used in the current study, factors which could be attributed to the different results found between the two studies.

In summary, the main question here is whether the birds could not discriminate what the two cues were signalling or whether delay to reinforcement does not have the same effect on behaviour as reinforcer magnitude does. As noted in the results, the birds pecked at each cue when they were presented during

the delay, indicating that the birds did attend to the cues. However, it appears that while the birds pecked at the cues, the pecking occurred more at the beginning of the retention interval and stopped for a while prior to the end of the retention interval, before an effective subsequent peck could occur. This resulted in the programmed and obtained retention intervals not matching. There was, however, no differential responding to the cues, both the cue for delay to reinforcement and the cue for no delay to reinforcement were pecked at similar rates. This suggests that the birds could see the cues on the screen but did not appear to have distinguished between the different colours. If there had been no pecking by any of the birds to either cue then it could be suggested that perhaps they could not see either or both cues. However, while the birds did peck at the cue during the delay, it appears that they slowed responding at the end of the retention interval when they were required to peck at the cue. The peck requirement at the end of the programmed retention interval inadvertently resulted in increasing the length of the retention intervals. Interestingly, despite the lengthened retention intervals, accuracy across all intervals for all birds remained consistently high, and as discussed earlier, were very similar to accuracy in the original DMTS. As mentioned, this suggests that the delay to reinforcement being present in the session did not have any effect on accuracy. While it appears that the birds responded with similar accuracy for both cues, Figure 14 provides evidence that suggests that the longest obtained retention intervals occurred on the delay to reinforcement trials, particularly at the 8-s delay interval, thus suggesting the cues did affect responding, although they did not affect accuracy. It is unclear why accuracy remained high given the lengthened retention intervals, but it is possible that due to there being a response requirement that this played a part in it. A possibly better baseline for comparison would have been to have had the response

requirement in the original DMTS training. This may have allowed us to see if inserting a delay to reinforcement was responsible for the slowed responding to the cue or if it was simply because they had to respond in order to finish the trial.

Given all of this, the same cues were used in the next experiment. The next experiment was a replication of White and Brown (2011) using signalled reinforcer magnitudes in place of delay to reinforcement. It was expected that the hens would show the signalled magnitude effect.

Experiment 3

This experiment replaced the signalled delay to reinforcement from the previous experiment with signalled reinforcer magnitude to see if response accuracy would differ on trials where the large reinforcer was signalled and where a small reinforcer was signalled.

Method

Subjects

The same five birds used in Experiments 1 and 2 served as subjects.

Apparatus

The apparatus used in Experiments 1 and 2 was the same for Experiment 3.

Procedure

There were two types of trials the hens were presented with in this condition: small reinforcer trials and large reinforcer trials. On the small reinforcer trials the hen was presented with the sample stimulus: a randomly selected red or green square. The hen was required to peck the sample 5 times which extinguished the sample and initiated a randomly selected retention interval of 1, 2, 4 or 8 s. During the retention interval a blue square (the cue) was shown in

the centre of the screen, approximately 3cm by 3cm in size. The cue remained in place for the duration of the retention interval. The first subsequent peck to the cue following the end of the retention interval removed the cue and presented the comparison stimuli: both a red and a green square and the hen was required to make a choice between the squares. Following a correct choice the hen received 0.5-s (small reinforcer) access to wheat as a reinforcer. Upon making a correct response, the hopper would rise but the reinforcer time of 0.5 s only began once the hens head entered the hopper and broke the infra-red beam. This allowed the hens to receive some food on the small reinforcer trials despite the short reinforcer duration. An incorrect response resulted in a blackout period and an intertrial interval of 10 s occurred at the end of each trial regardless of the outcome.

On the large reinforcer trials the hens followed the same sequence of events as on the small reinforcer trials but during the retention interval a yellow square (the cue) was presented on the screen. A correct response resulted in a 4.5-s (large reinforcer) access to wheat. Upon making a correct response the hopper would rise and the reinforcer time would start once the hens head entered the hopper, breaking the beam. An incorrect response resulted in a blackout period. An intertrial interval of 10 s occurred at the end of each trial regardless of the outcome during which the screen was black with nothing presented on it.

Results

Figure 15 shows the mean of the $\log d$ for the small reinforcer, indicated by the circles, and large reinforcer, indicated by the squares, across retention intervals for all birds. The mean of the $\log d$ across all birds was consistent between 1.0 and 2.0. There were no consistent differences between $\log d$ for the two cues across birds. Birds 11.1 and 11.2 had lower $\log d$ values for the larger

reinforcer, bird 11.4 had higher $\log d$ values for the larger reinforcer, while birds 11.3 and 11.6 had no consistent differences in $\log d$ values over reinforcers. Mean $\log d$ did not trend consistently over retention intervals for either cue for all birds.

The mean $\log c$ for all birds for the small reinforcer, shown by the circles, and large reinforcer, shown by the squares, across all retention intervals is shown in Figure 16. $\log c$ values for all birds were consistent between 0 and 1.0 for both the small reinforcer and the large reinforcer, showing slight biases towards the red key for all birds. There were no consistent differences in $\log c$ values for the two cues for all birds. Bird 11.6 showed small but consistent differences in $\log c$ for the first three retention intervals for the small and large reinforcer.

Figure 17 shows percent correct for the small reinforcer and the large reinforcer across all retention intervals for all birds. Across all birds percent correct fell between 60 and 80%. It was 60 – 70% for the 8-s retention interval across all birds. Percent correct did not differ consistently for the two cues for any bird over all retention intervals.

A comparison between the mean $\log d$ values for delayed matching to sample (Experiment 1) and mean of the $\log d$ for the small reinforcer and large reinforcer across retention intervals for all birds is shown in Figure 18. The $\log d$ values for both the small reinforcer and large reinforcer do not differ consistently from the $\log d$ values from Experiment 1 for birds 11.1, 11.2 and 11.6. For birds 11.3 and 11.4 the Experiment 1 $\log d$ values tend to be lower at all retention intervals, showing these hens were more accurate in this present experiment.

Figure 19 shows the cumulative number of pecks the hens made to each of the cues during the retention intervals. The number of pecks ranged between 20

and 80, with the exception of the fifth session for 11.6 where pecks to both cues were below 10. There was no consistent pattern or trend to the cue pecking, but the numbers are variable across sessions with the data from 11.2 showing the most variance.

Figure 20 shows the obtained lengths of the retention intervals plotted against the programmed retention intervals. Overall, all the programmed retention intervals were increased in length as a result of the birds not responding immediately when the programmed delay terminated. There were no consistent trends in these data with either cue. With the exception of 11.2, the biggest increase in programmed retention interval length occurred at the 8-s retention interval across all birds. The length of the obtained retention interval did not change consistently with size of the reinforcers for any retention interval or hen. The largest increase in programmed retention interval length was for 11.2 at the 1-s interval for the large reinforcer.

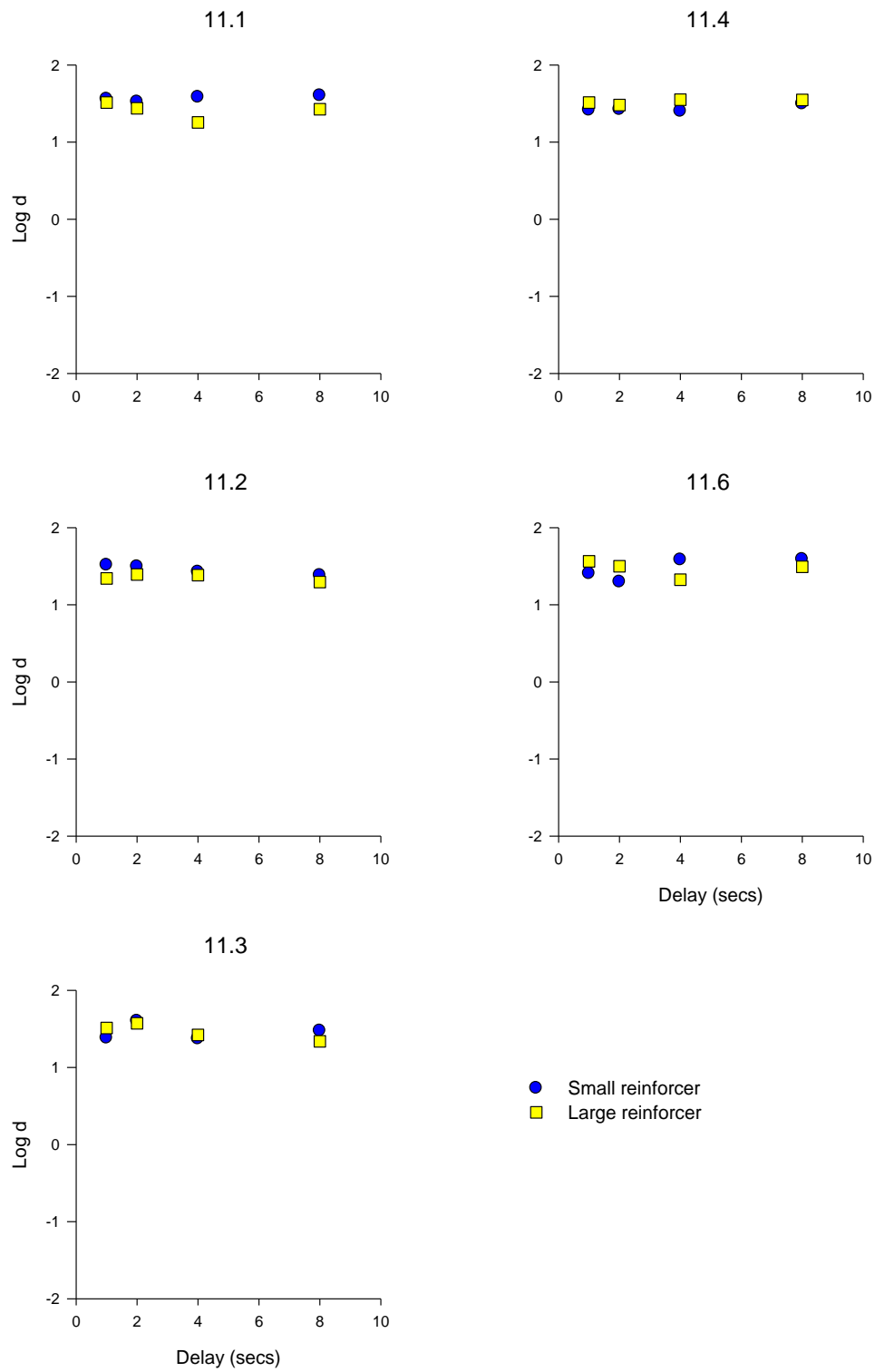


Figure 15: Mean log d values for each cue across all retention intervals for the small reinforcer and the large reinforcer from the last 12 sessions for all birds.

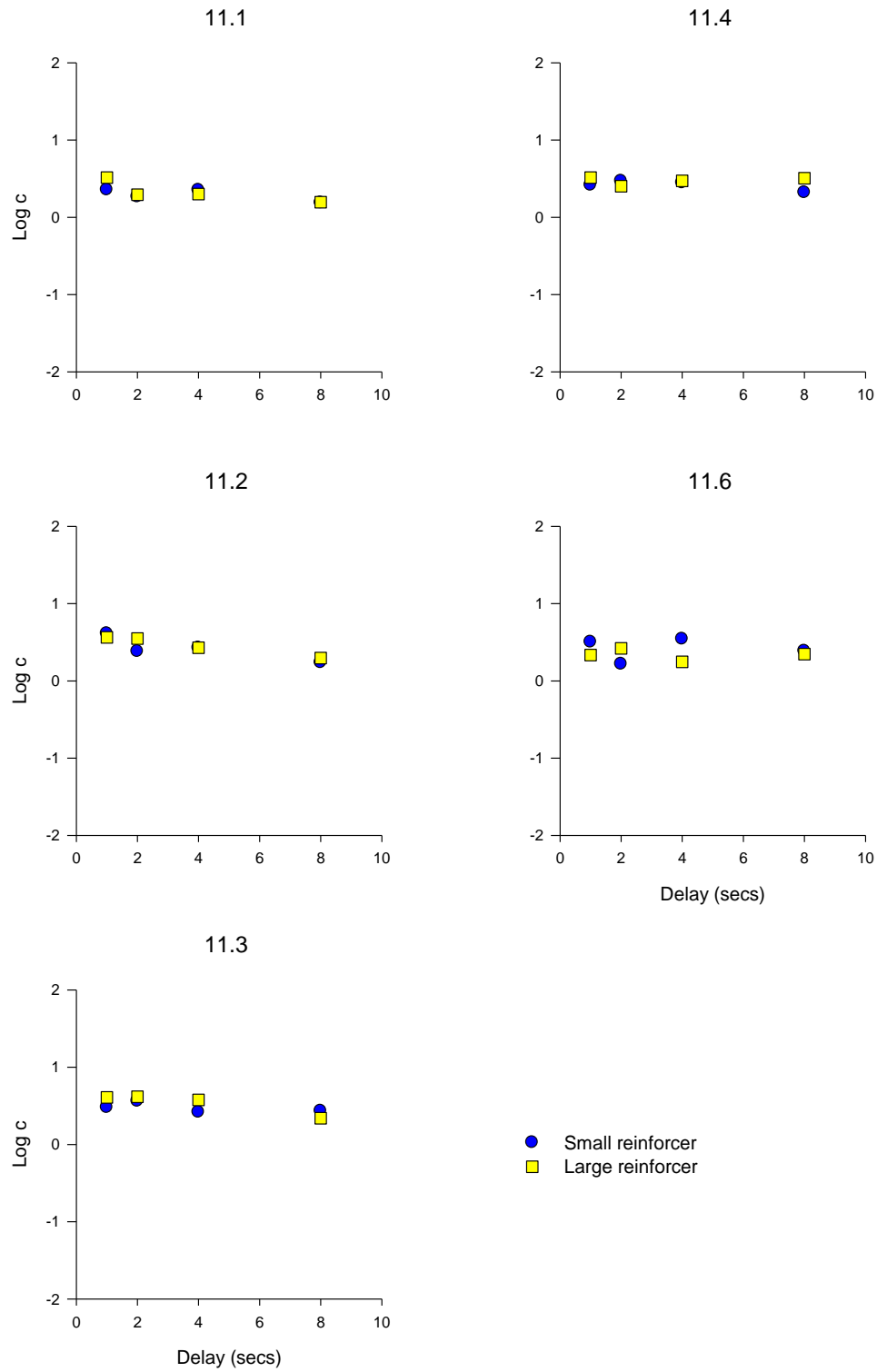


Figure 16: Mean log c for the small reinforcer and large reinforcer across all retention intervals from the last 12 sessions for all birds.

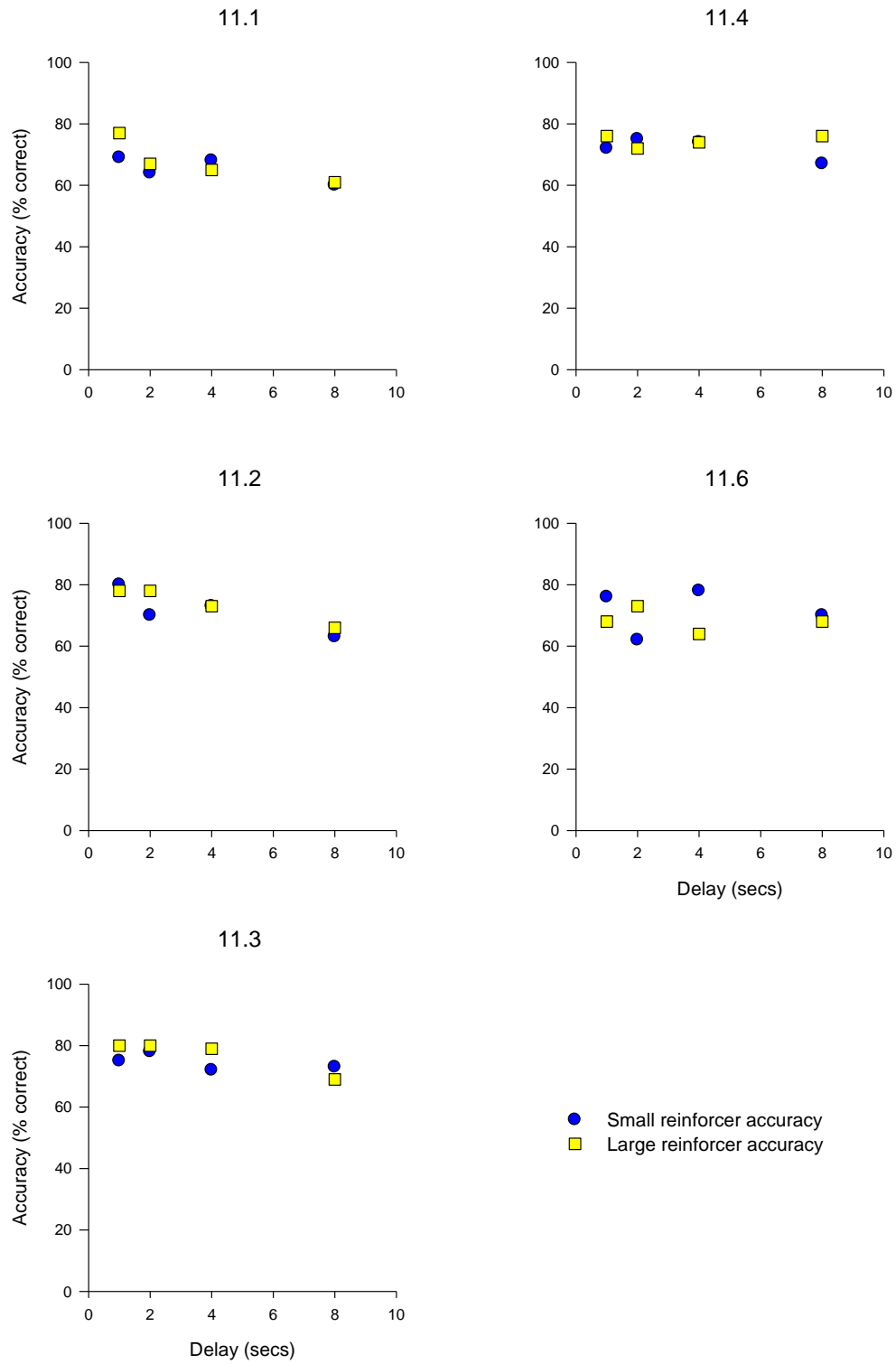


Figure 17: Mean percent correct for the small reinforcer and large reinforcer across retention intervals from the last 12 sessions for all birds.

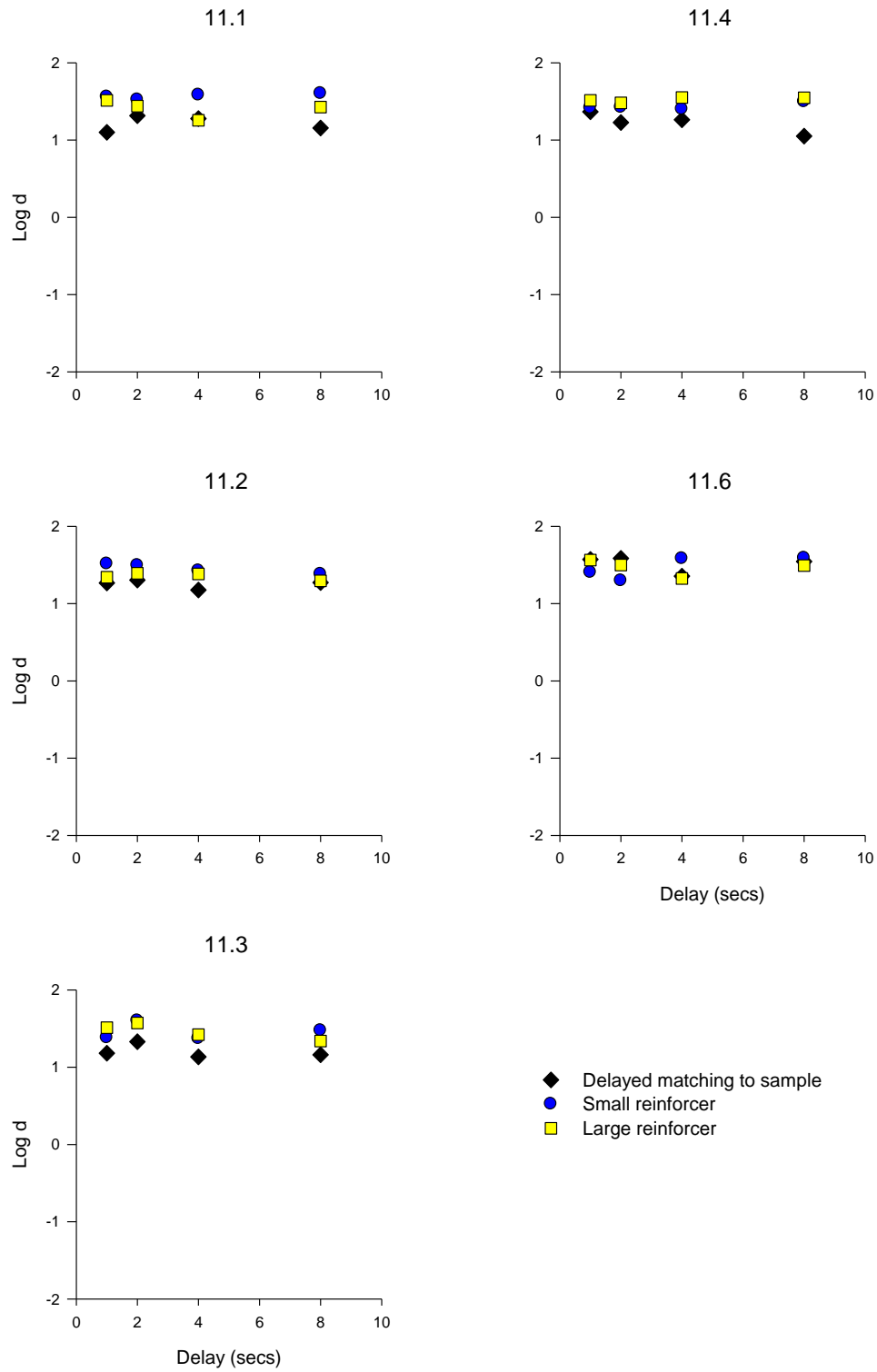


Figure18: Mean $\log d$ from the last 6 sessions of Experiment 1 and the mean $\log d$ from the last 12 sessions with the small reinforcer and large reinforcer plotted across retention intervals for all birds.

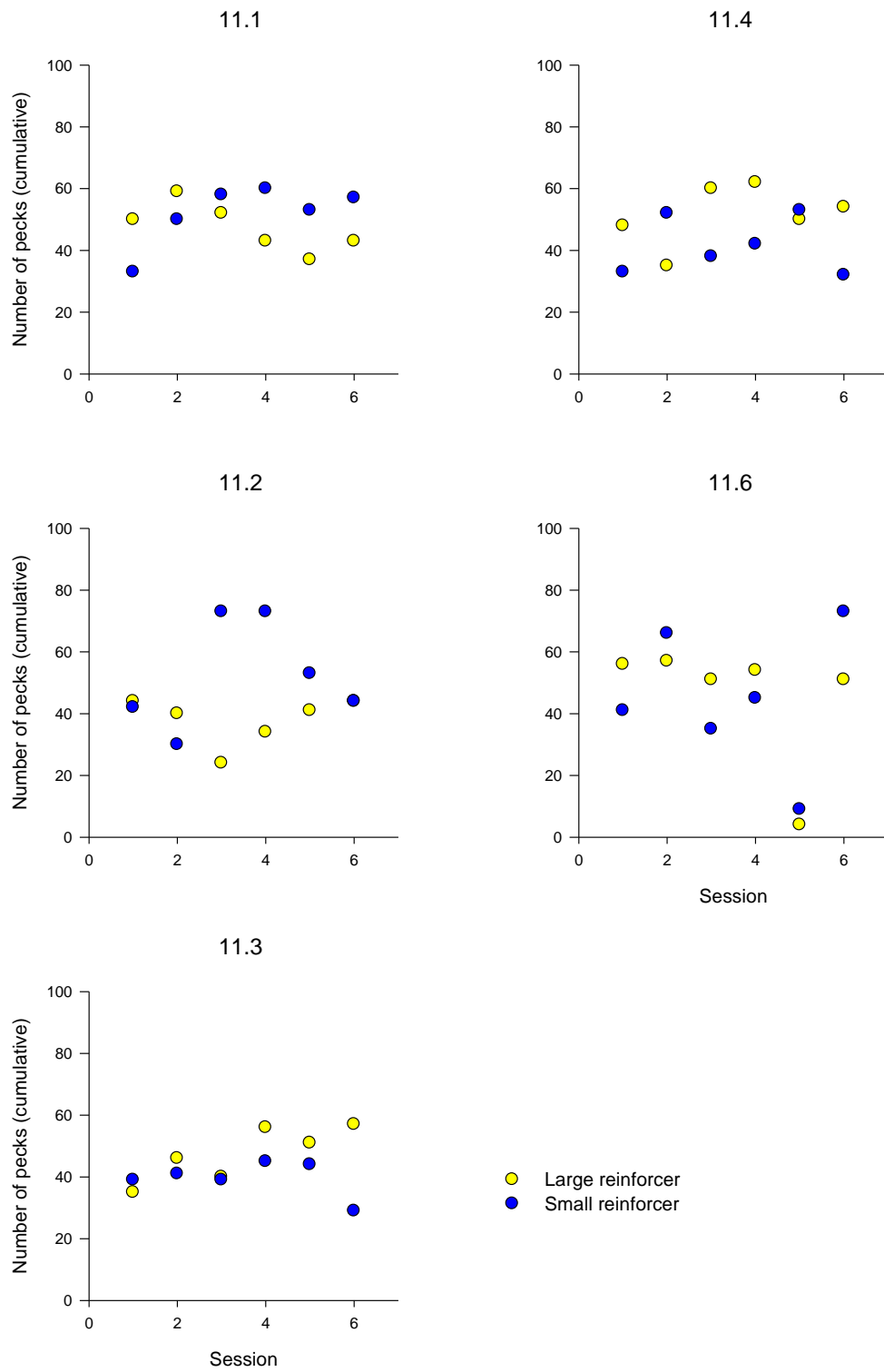


Figure 19: Total number of pecks to each cue for signalled magnitude from the last 6 sessions for all birds across all retention intervals.

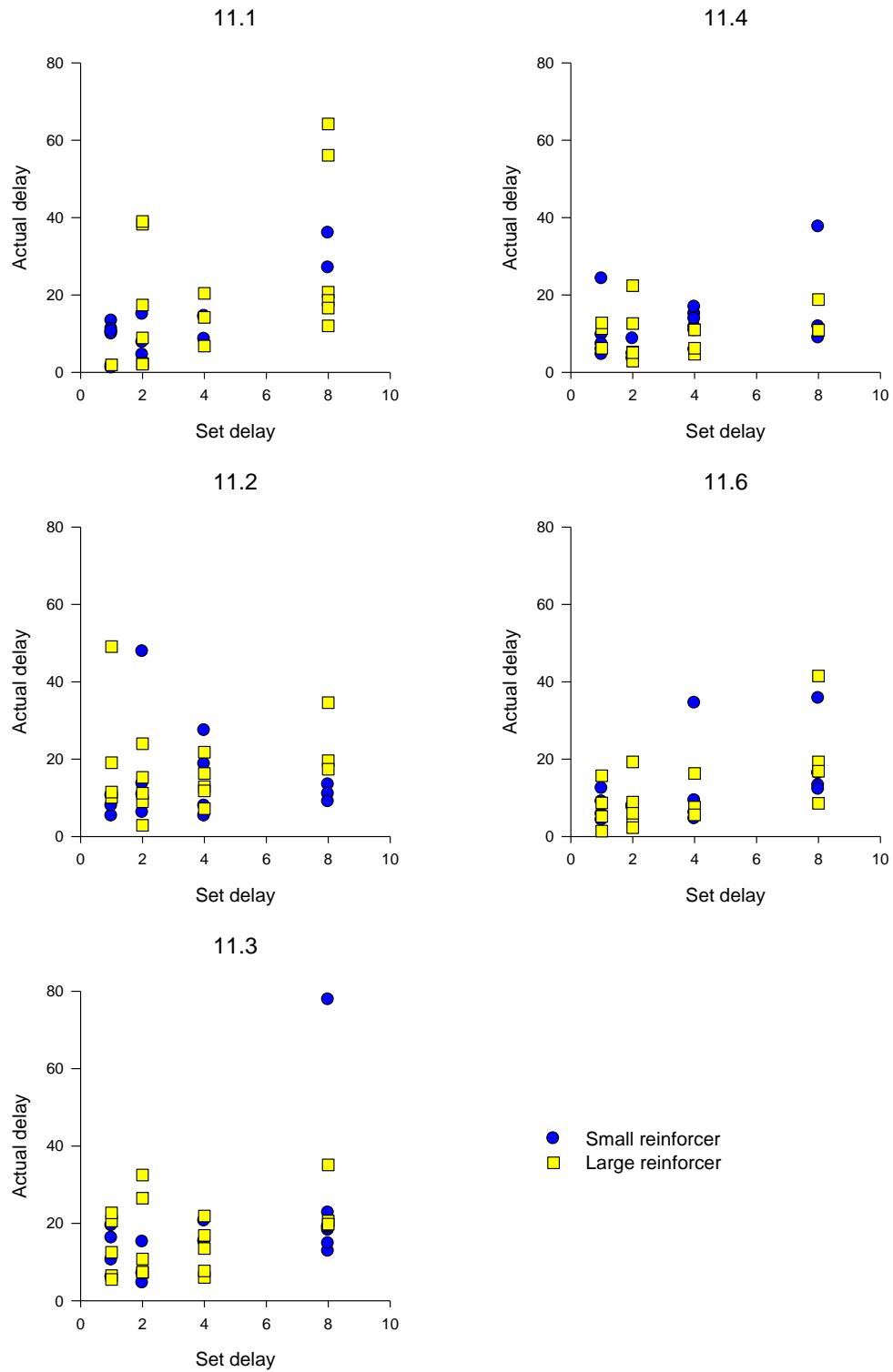


Figure 20: Obtained retention interval lengths against programmed retention interval lengths for the small reinforcer and large reinforcer across all birds for all retention intervals.

Discussion

Overall, the results of the signalled magnitude condition show that whilst discrimination between the red and green keys remained high, discrimination between the cues signalling the small and large reinforcer appears not to have taken place. The lack of significant difference between the mean $\log d$ values for both reinforcer sizes indicates that the cue did not have an effect on within trial sessions: the birds continued to maintain high rates of matching regardless of the reinforcer size that was being signalled. The small difference in the means for DMTS and the reinforcer sizes suggests that inserting the cues into the retention intervals did not affect a change in response behaviour, despite the sizable difference in reinforcers.

Signalled reinforcer magnitude was used as an alternative to signalled delay to reinforcement in an attempt to affect a change in response behaviour. By using differential reinforcer magnitudes it was hypothesised that accuracy on trials where the large reinforcer was signalled would increase, and that accuracy on trials where the small reinforcer was signalled would decrease.

As mentioned earlier, White and Brown (2011) signalled different reinforcer magnitudes and found that accuracy increased when the large reinforcer was signalled and decreased when the small reinforcer was signalled. This outcome was named the Signalled Magnitude Effect. The present study used the same reinforcer magnitudes that White and Brown (2011) used but found no difference in accuracy between the small and large reinforcer.

Possible reasons for this again lie in the training method discussed in the previous conditions. As with the signalled delay to reinforcement condition,

accuracy across all birds remained high regardless of the cue that was signalled. Performance accuracy also maintained high rates at the longer retention intervals.

However, the fact that the birds failed to show any difference in accuracy between the signalled magnitude condition and the signalled delay to reinforcement condition, indicates that the cue was not recognised for what it was. The insertion of the cue during the retention interval had no effect on response behaviour: this is shown by the lack of difference in accuracy between the delayed matching to sample data, which provides a baseline measure, and the signalling conditions. However, as mentioned in the results, the birds did attend to the cues by pecking at them during the retention intervals which suggests that they can see the cues. This suggests that perhaps discrimination was occurring between the cues but that the reinforcer magnitude had no effect. The birds pecking at the cue indicates that some response behaviour was occurring during the retention interval. It appears that responding to the cue was more variable and occurred at a higher rate during the reinforcer magnitude experiment than the delay to reinforcement experiment. As with signalled delay to reinforcement, the programmed retention intervals for signalled reinforcer size increased, at times quite significantly, as a result of the birds taking a long time to respond at the end of the retention. However, in contrast to the previous experiment, there was no evidence to suggest that this differed between trial types.

It is possible that that signalling reinforcer magnitude had a greater effect than that of signalling delay to reinforcement but the overall effect was not great enough to affect a change in response behaviour in regards to matching.

Another reason for the birds failing to discriminate between the cues may lie in the cues themselves. The cues that were used for signalling may not have

been salient enough for the hens to learn the discrimination. The cues, although different in colour and with geometric shapes, were the same shape (a square) and size as the sample stimuli. The use of a completely different stimulus may have had more effect.

Nevin and Grosch (1990) found the signalled magnitude effect in their study: accuracy was higher on trials that signalled the larger reinforcer. In their study, they correlated different auditory stimuli with the different reinforcer magnitudes. Given that the birds were responding on keys, the auditory stimulus was a completely different form of stimulus which resulted in the birds learning to discriminate between the different auditory cues. It is possible that we had used a more salient cue for signalling the birds would have responded in a different way.

As a result of the cues failing to change behaviour the condition utilising switch trials did not occur. If any effect had occurred from signalling delay to reinforcement or signalling magnitude, it was intended that the cues would be switched partway through the retention interval in order to determine if a reversal in response behaviour would occur. Due to no significant findings in the signalling conditions we had no grounds to proceed with the switch trials.

Summary and Conclusions

One aim of the current study was to examine whether a signalled delay to reinforcement would act similarly in a DMTS procedure to the way White and Brown (2011) found that signalled reinforcer magnitude did. It was hypothesised that signalling a delay to reinforcement on some trials would result in a decrease in accuracy on those trials as signalling a reinforcer does. However, adding the signalled delay to reinforcement had no effect on accuracy either over the whole session or on delay trials. It was decided that the next step would be to attempt to show the signalled magnitude effect by replicating the procedure used by White and Brown (2011). Changing the magnitude of the reinforcer on some trials and signalling this change had no effect on accuracy either on these trials or over the whole session.

The lack of effect of the delay to the reinforcer was unexpected. Cox and D'Amato (1977) report that introducing a delay to reinforcement in a well learned discrimination results in significant deterioration in response accuracy which gets worse the longer the delay to reinforcement is. They suggested that this is due to the incentive value of the reinforcer decreasing. Theoretically, incentive loss should have applied to the current study with the delay to reinforcement; however, it may be that the delay to reinforcement used was too short to have an effect. The current study used a 2.5-s delay, whilst Cox and D'Amato (1977) reached a delay of 128 s. Cox and D'Amato (1977) reported a significant deterioration in accuracy after using long delays to reinforcement, as well as reporting that accuracy did not recover after the delay was removed. Thus, one direction for further study would be to increase the length of the delay used.

However, given there was no consistent difference in accuracy between the delay to reinforcement and no delay to reinforcement trials, it was decided to see whether the signalled reinforcer magnitude effect could be replicated. The reinforcer magnitudes signalled in this condition were the same as magnitudes used by White and Brown (2011). Results again showed no consistent differentiation between the cues signalling the different reinforcers.

Thus, inserting the cues into the retention interval so that they signalled a delay to reinforcement or the different magnitudes of the reinforcer did not affect accuracy. In fact accuracy remained consistently high across all delays regardless of what the cues were signalling. As reported earlier, the birds responded to the cues during the retention intervals in both Experiment 2 and 3 providing evidence that the birds were aware of the presence of the cues, thereby eliminating the possibility that the birds could not see them. Responding to both cues occurred at similar rates, suggesting that the cues were both visible.

The lack of changes in accuracy in both experiments could be a result of either the hens not being able to discriminate the cues or by there being no effect of the different reinforcement contingencies. As reported earlier, that the birds responded during the retention interval shows they could see the cues, and so it may be the differential reinforcement that the cues signalled had no effect on behaviour.

There are several possible reasons as to why this may have occurred. As discussed earlier, this could have been a result of the gradual training with each delay that the hens received prior to performing on the final DMTS task. Training at each delay was increment until stability was achieved provided the birds with a lot of exposure to the stimuli and as a result they had a lot of practice responding

on the task. Adding to this, White (in press) discusses the theory of temporal independence: that performance at shorter delays is independent of performance at longer delays. This suggests that remembering is specific to the delay at which it occurs. White (in press) states that this indicates that remembering does not occur at the time of discrimination but at the time of learning. The lack of differences in accuracy in Experiment 1 across the delays supports this idea as accuracy did not decrease with longer retention intervals: the results of Experiment 1 contradict the usual findings of DMTS procedures. That accuracy remained consistently high even at the longer retention intervals in Experiment 2 and 3 further supports this theory and indicates that delay specific remembering occurred as accuracy was specific to the delays at which it occurred. As accuracy remained high across all retention intervals it can be argued that the hen's remembering occurred at the time of learning. The hen's learning took place during DMTS training, in which they were gradually introduced to longer retention intervals. This gradual introduction appears to have supported the hen's learning and as such their ability to remember.

In terms of exposure, another consideration lies in the FR requirement on the sample stimulus: the birds were required to respond to the sample stimulus on an FR5. White (in press) states that a fixed ratio response requirement makes the birds attend longer to the sample stimulus, thereby facilitating stimulus control. The response requirement increases the amount of time the birds are exposed to the sample stimuli; therefore the FR requirement on the current study may have contributed to the high rates of accuracy seen through all conditions. This is supported by the conclusions of Odey (1991), as explained below.

Odey (1991) compared data from studies that used an FR1 sample requirement on a DMTS with hens to those from her study which had an FR5 sample requirement, also a DMTS with hens. She observed higher discrimination and smaller decrements in accuracy with increases in delay with the FR5 sample requirement, suggesting that increases in the FR requirement affected discrimination. White (1985) also found that decreasing the FR on the sample led to a decrease in discrimination. As mentioned above, White (in press) argues that remembering does not take place at the time of discrimination but rather at the time of learning. The point of initial learning is the interaction with the sample stimulus. The FR 5 requirement allows for longer discrimination at this point of learning and therefore is likely to aid accurate responding.

Another procedural factor that may have added to the accuracy here is the intertrial interval. Both Odey (1991) and White (1985) report higher discriminations for longer intertrial interval lengths, although they state that the reasons for this are unclear. Odey (1991) compared the use of no intertrial interval (0 seconds) with a 10 s intertrial interval and found that discrimination was higher and showed a smaller decrement in discrimination across delay intervals. The current study used an intertrial interval of 10 s which may have contributed to the high rates of accuracy.

In a procedural limitation in Experiment 2 and 3, the required subsequent peck to the cue resulted in lengthening the delay interval. The first subsequent peck after the delay had ended was required in order to initiate the comparison stimuli. However, the hens had no way of discriminating when the programmed interval had ended. Although the birds continued to peck at the cues during the delay, a peck to the cue once the delay had ended often did not occur for several

seconds after the end of the programmed interval, thus increasing the length of the retention interval. . White and Brown (2011) refer to possible latencies in responding to the cue during the retention interval in relation to the switch trials they carried out. These switch trials were only carried on the 4-s and 8-s intervals, the cue for the 1-s and 2-s retention intervals did not change “even if the delay was extended beyond the arranged 1-s or 2-s delay owing to a longer response latency” (p.8). In the current study this latency to respond to the cue at the end of the interval theoretically had the potential to affect the accuracy of the birds matching. However, the lengthening of the interval did not appear to have affected the accuracy of the birds in any way. The obtained retention intervals, however, provided limitations on the interpretation of data as the delay interval lengths were often potentially longer than they were programmed to be. In terms of the lengthened retention intervals, future research may consider using some form of cue, such as an auditory tone, to indicate the end of the retention interval has occurred. This may reduce the possibility of inadvertently lengthening the retention intervals passed the programmed intervals.

Overall, the results of the present study may have been due to a combination of procedural factors that potentially had an effect on the behaviour of the birds. White (in press) described the complex stimulus that makes up the to-be-remembered event: he states that each aspect of the event (the sample, delay intervals, comparison stimuli, reinforcement and intertrial interval) together exert control over the response behaviour. Responding becomes delay specific as a result. The occurrence of delay specific remembering from Experiment 1 may be a reason why the cues had no effect on behaviour: if the cues had been inserted during training there may have been an effect by delay to reinforcement and/or reinforcer magnitude.

Due to time constraints on the current study we were unable to carry out further experiments in order to examine the possible effects of the different procedural factors. Examining the effects of different procedural factor combinations such as different FR sample requirements, intertrial interval lengths and delay interval lengths may have provided evidence as to why the signalling of differential reinforcement had no effect, and such studies would also extend the work of Breen (1987).

Adding to this, if time had allowed, it would have been sensible to examine different methods of delay training. Training the birds at the final delay lengths from the beginning rather than gradually increasing the delay lengths may have produced different results. Starting the experiment without any delay training may have eliminated the development of temporal independence and delay specific remembering so early in the study, which would have reduced the carry over effect. However, the occurrence of temporal independence in the current study as a potential result of the training method that was used may provide an interesting starting point for further research. Generalisation to similar delays as was seen in Experiment 1 may have been minimised and the length of time the birds were exposed to the stimuli decreased by not using delay training. A decrease in exposure would have meant less practice and perhaps lower accuracy levels. Starting the DMTS procedure without delay training would have provided much more time to explore the other possible avenues mentioned above in order to compare the use of different aspects of the manipulations and procedural factors.

References

- Blough, D. S. (1959). Delayed matching in the pigeon. *Journal of the Experimental Analysis of Behavior*, 2, 151-160.
- Breen, T. M. (1987). Delayed matching to sample: the relevance of training to stability. Master's thesis, University of Waikato, Hamilton.
- Brown, G. S., & White, K. G. (2005). On the effects of signalling reinforcer Probability and Magnitude in delayed matching to sample. *Journal of the Experimental Analysis of Behavior*, 83, 119-128.
- Brown, G. S., & White, K. G. (2009). Reinforcer probability, reinforcer magnitude and the Reinforcement context for remembering. *Journal of Experimental Psychology: Animal behavior*, 35, 238-249
- Cooper, J. O., Heron, T. E., & Heward, W. L. (2007). *Applied Behavior Analysis* (2nd ed.). New Jersey: Pearson Prentice Hall.
- Cox, J. K., & D'Amato, M. R. (1977). Disruption of overlearned discriminative behavior in monkeys by delay of reward. *Animal Learning & Behavior*, 5, 93-98.
- Etheredge, R. J. M. (1997). Delayed matching to sample: the effects of delaying reinforcement at a single post-sample stimulus delay. Master's thesis. University of Waikato.
- Fetterman, J.G. (1995). The psychophysics of remembered duration. *Animal Learning & Behavior*, 23, 49-62.
- Harper, D. N., & White, K. G. (1997). Retroactive interference and rate of

- forgetting in delayed matching to sample performance. *Animal Learning & Behavior*, 25, 158-164.
- Harnett, P., McCarthy, D., & Davison, M. (1984). Delayed signal detection, differential reinforcement and short term memory in the pigeon. *Journal of the Experimental Analysis of Behavior*, 42, 87-111.
- Hautus, M. J. (1995). Corrections for extreme proportions and their biasing effects in estimated values of d' . *Behavior Research Methods, Instruments and Computers*, 27, 46-51.
- MacDonald, S. E., & Grant, D. S. (1987). Effects of signalled retention interval length on delayed matching to sample in pigeons. *Journal of Experimental Psychology: Animal Behavior Processes*, 13, 116-125.
- Martin, G., & Pear, J. (2007). *Behavior Modification: what it is and how to do it* (8th ed.). New Jersey: Pearson Prentice Hall.
- Mazur, J. E. (1991). Choice with probabilistic reinforcement: effects of delay and conditioned reinforcers. *Journal of the Experimental Analysis of Behavior*, 55, 63-77.
- McCarthy, D., & Voss, P. (1995). Delayed matching to sample performance: effects of Relative reinforcer frequency and signalled reinforcer and signalled versus Unsignalled reinforcer magnitudes. *Journal of the Experimental Analysis of Behavior*, 63, 33-51.
- Nakagawa, S., Etheredge, R. J. M., Foster, T. M., Sumpter, C. E., & Temple, W.

- (2004). The effects of changes in consequences on hen's performance in delayed matching to sample tasks. *Behavioural Processes*, 67, 441-451.
- Nevin, J. A., & Grosch, J. (1990). Effects of signalled reinforcer magnitude on delayed matching to sample performance. *Journal of Experimental Psychology: Animal Behavior Processes*, 16, 298-305.
- Odey, M. (1991). DMTS with hens: the effects of some procedural variations. Master's thesis, University of Waikato, Hamilton.
- Sargisson, R. J., & White, K. G. (2001). Generalization of delayed matching to sample following training at different delays. *Journal of the Experimental Analysis of Behavior*, 75, 1-14.
- Sargisson, R. J., & White, K. G. (2007). Timing, remembering and discrimination. *Journal of the Experimental Analysis of Behavior*, 87, 35-37.
- Stubbs, A. (1968). The discrimination of stimulus duration by pigeons. *Journal of the Experimental Analysis of behavior*, 11, 223-238.
- Tulving, E., & Thomson, D.M. (1971). Retrieval processes in recognition memory: effects of associative context. *Journal of Experimental Psychology*, 87, 116-124.
- Wasserman, E. A., Grosch, J., & Nevin, J. A. (1982). Effects of signalled retention intervals on pigeon short term memory. *Animal Learning & Behavior*, 10, 330-338.
- Weavers, R., Foster, T. M., & Temple, W. (1998). Reinforcer efficacy in a delayed matching to sample task. *Journal of the Experimental Analysis of*

Behavior, 69, 77-85.

- White, K. G., & Cooney, E. B. (1996). Consequences of remembering: independence of performance at different retention intervals. *Journal of Experimental Psychology: Animal Behavior Processes*, 22, 51-59.
- White, K.G. (2001). Forgetting Functions. *Animal Learning & Behavior*, 29, 193-207.
- White, K.G. (2002). Psychophysics of remembering: the discrimination hypothesis. *Current Directions in Psychological Science*, 11, 141-145.
- White, K. G. (in press). Remembering and Forgetting. In G.J. Madden (Ed.), *APA Handbook of Behavior Analysis (Vol. 1.): Methods and Principles*. American Psychological Association.
- White, K. G., & Brown, G. S. (2011). Reversing the signalled magnitude effect in delayed matching to sample: delay-specific remembering? *Journal of the Experimental Analysis of Behavior*, 96, 7-15.

Appendix A

Please find the attached CD containing the data files and notes from the current study for the matching-to-sample and delayed matching to sample conditions from Experiment 1.

Appendix B

Please find the attached CD containing the data files and notes from the current study for signalled delay to reinforcement from Experiment 2 and signalled reinforcer magnitude from Experiment 3.